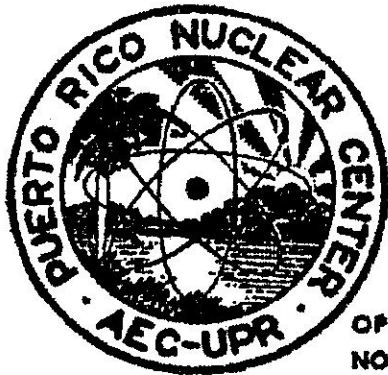


# PUERTO RICO NUCLEAR CENTER

AN ELECTRICAL NETWORK MODEL  
OF THE RAIN FOREST ECOLOGICAL SYSTEM



OPERATED BY UNIVERSITY OF PUERTO RICO UNDER CONTRACT  
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Puerto Rico Nuclear Center  
Rio Piedras, Puerto Rico

Plan for a Research Tool and Exhibit  
AN ELECTRICAL NETWORK MODEL OF THE RAIN FOREST ECOLOGICAL SYSTEM

An electrical portrayal of energy and carbon  
circuits of principal compartments  
of any ecosystem

by  
Howard T. Odum

July 15, 1965

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## FOREWORD

Because a functional exhibit is needed to portray the AEC rain forest project at El Verde, Puerto Rico and because a research model of an ecological system is needed in that work to explore temporal aspects of ecological food chain networks, a plan is provided for an electrical analog for both purposes. The model involves some theoretical equivalences between ecological and electrical circuits as previously published. When built it will be the fourth in a series of ecosystem models each of increasing complexity. If two are built, research and exhibit purposes can be served now without delay.

H. T. Odum

## ABSTRACT

This is a plan for an electrical model of an ecological network in which the electric current (amperage) represents the flow of carbon, the storage of electrons (condensor voltages) represents the stored quantities of organic fuel, and the dispersal of energy into heat occurs in pertinent places as with the flows of the real system. The model is usable for exhibit and research purposes.

Using serrations and holes in a large rotating disk, a program of input of light is received on silicon photocells so as to provide 5 channels and compartments of plant photosynthesis and 5 channels of non-photosynthetic input. The photosynthetic inflows follow rectangular hyperbolas with light intensity and then are amplified to the 0 to 100 voltage range to reduce costs of metering elsewhere in the model. Twenty channels of consumers are provided with pin jack connections so that any combinations can be arranged. For example, 5 species of plant respiratory systems, 5 species of herbivores, 5 species of carnivores, and 5 species of tertiary consumers can be interconnected. Each consumer module has a milliammeter to indicate input flow and one to indicate the respiratory flow of metabolism accompanying necessary work of the function. Provision is made to add through plug-in units and jumpers such characteristic features of consumer populations as the one-way valve, the logistic feedback, the extinction relay, or the immigration start. Five channels of export are provided with monitoring milliammeters. An electron voltmeter is provided for the monitoring of organic storages in compartments of the system, using plug-in jacks as needed. A control panel includes a strip chart recorder for either flows or storages as desired. In the model designed for exhibit purposes, a display section is added that includes an energy diagram, a three dimensional model of a forest with some of the features identified, and some posters of instructions.

The exhibit model has the 5 special inputs programmed to simulate the effect of gamma irradiation on a forest in first reducing productivity, followed by a recovery of photosynthesis with low diversity and a return to normal. The observer with control buttons may operate the exhibit first as a normal forest and then through the radiation sequence. Judging by some earlier models, the message of matrix magnificence of an ecological network is portrayed in a way that appeals to ecologist and casual visitor alike. The model also provides for testing of many hypotheses about the relation of inputs to system responses.

## Introduction

The electrical simulation of network functions is now a widespread and rapidly evolving method for dealing with the complex synthetic sciences involving the interactions of many functional units. The great systems of nature are complex systems of functionally interconnected compartments about which many data are being obtained as to structure and function. It is natural that synthesis of data known about parts should be attempted with network simulation, that various hypotheses be tested through such models, and that such models might show visibly the complex interplay of flows that are usually almost invisible in the forest or sea.

Simulation in somewhat related physiological systems is an advanced art mainly with operation-analog mathematical methodologies (Chance, 1959 French and Fork, 1961, Shepard, 1962). Some of these methods have been applied to ecological systems by Olsen (1963); Neel and Olsen (1962); Patten (1965); and Electronic Associates (1965).

For the most part these methods involve the simulation of modules whose mathematical functions are set out first, and whose temporal consequences are then observed. Generally, voltage represents a quantity, but amperage and energies involved in the electrical system are not analagous to those of the ecological system.

There is another approach in which the flows are kept analagous using circuits whose pathways each have comparable significance in the environmental network. Such an electrical model readily portrays food flows and metabolism and is close to the language already in use in the study of ecological food webs. This prospectus plans a further development of an ecological model along this flow principle.

## Theoretical Basis

The use of the passive electrical analog for energy and carbon flow representations in ecological systems was partly given briefly in three previous publications (Odum, 1960, 1962, 1964). Because the flows of carbon in food chains and other movements in natural systems can be shown to be in proportion to the organic concentration up-circuit in many instances, there is a basic analog to Ohms law that may be stated in equation 1 and in Table 1.

$$J = \frac{1}{R}N \quad (1)$$

Since the potential energies for the driving concentrations in these kinds of systems are within about 15% of being constant per unit weight they are unlike solution chemical systems. The potential function is mainly proportional to the concentration rather than the logarithm of it. Hence the flow (J) is proportional to the potential and to the organic food concentration (N). Hence the electrical model has voltage in proportion to concentration and also in proportion to storage potential; current (J) is in proportion to carbon flow; and energy flow is proportional to the product of the current (J) and the caloric value of the carbon flow being modelled in that segment (u). The loss of heat from electrical resistances and other units of the model is in proportion to the loss of heat in the equivalent irreversible processes of the real ecosystem. The energy stored and flowing in the electrical system has no meaning for the ecosystem, since the potential function for electrons is different from that for packaged chemical potential energy. The question about flow being proportional to concentration or to log of concentration raised in the 1960 paper has since been resolved as stated in this section.

Whereas the flow of carbon and energy is in proportion to the concentration and potentials of the up-circuit storage, it is not proportional in the same way in every circuit since the driving impetus to the circuit flow depends on the form and protective work spent in the biological storing process. Hence the pounds of organic matter in elephants drive the consumption of elements differently from that in insects, fish, leaf litter, and waters containing dissolved glucose.

TABLE 1.

Table of equivalents with useful analogs encircled\*

	Circuit of a Population of Components	Passive Electrical Analog
Driving Impetus	Thrust: N	Voltage X
Potential Energy Stored	$uc'N$	Condensor charge $\frac{q^{2**}}{C}$ energy
Flux	Carbon Flux: J'	Amperage J
Power Transmitted	$uJ'$	J X**
Causal Law	$J = \frac{1}{R} N$	Ohms Law $J = \frac{1}{R} X$
Storage Capacity	$C' = \frac{q'}{N}$	$C = \frac{q}{X}$

\* q is quantity of electrons and q' of organic carbon; u is the chemical potential energy per mole of organic carbon flowing; R is resistance in ohms.

\*\* Items double-starred in the electrical system have no significance in the biological system, since the relation of energies to flux and storage differ.



The driving impetus was termed ecoforce in the 1960 paper, but it might better be called thrust impetus since it is not one force but the effect of a population of constant microscopic forces, each of which is a molecular reaction acting separately.

The correct analogs for a simple electrical circuit are given in Table 1. The consequence of this theory is that any passive electrical model involving conductances, storages, time-lag units, feedbacks, etc. can be scaled to an ecological system as long as the encircled comparisons are made. Whenever, the real system does not have the linearity of equation 1, the system becomes a qualitative model only. The approach allows one to design circuits for comparing model function with observed ones. Working towards increasing complexity in the model, one may identify each insulated circuit as a compartment or function of the ecological system such as sun leaves, shade herbs, dominant tree species, etc. As knowledge and actual measurements in the real environment increase, the compartments and the circuits representing groups of species are replaced by one circuit for each species thus duplicating in the electrical model the degree of separation of nature's insulation process, which we usually call species or organ isolation. The broad brush picture of a simple model can become the detailed model of the real system with matrices involving several hundred component modules. The model serves as a rallying point for ecological synthesis, which is the most difficult problem in environmental science. Biogeochemistry, productivity, autecology, population growth and death, and control behavior are all represented in the model.

In the rain forest there are many hundreds of species even in a prism of minimum size for functional operation. Previous prototypes of these network models involved only 8 compartments and circuits. The model given in this plan provides for a matrix of 20 compartments, 10 inputs and 5 outputs, a number somewhat comparable with the detail in which the forest data are being obtained.

#### Main Units of the Model

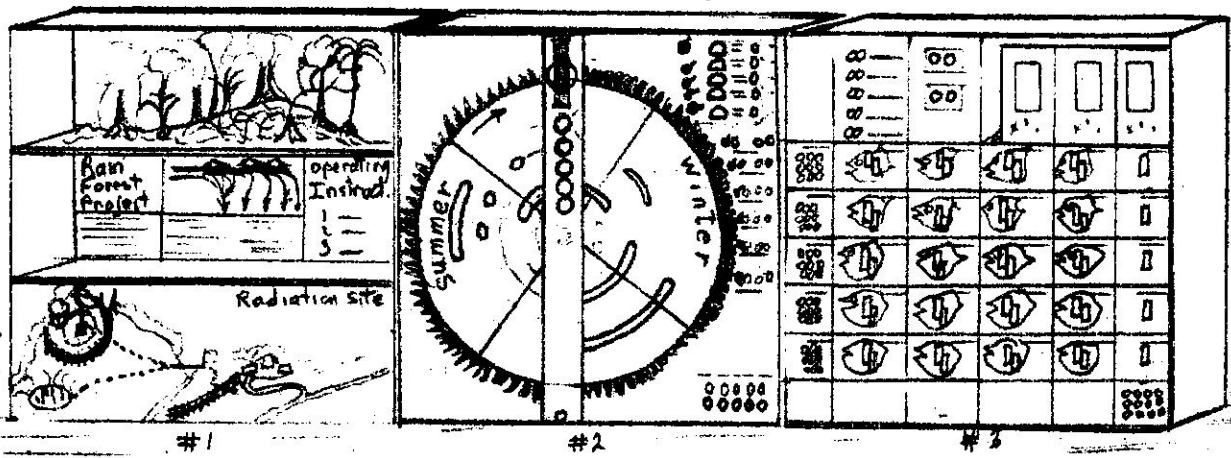
The main units are sketched in Fig. 1. Unit #1 is a cabinet containing explanations and three dimensional models of the forest. Unit #2 is a cabinet containing the main programming disc that rotates and permits lights to fall on photocells through silhouettes, slots, and holes so as to provide a program of inputs. Unit #3 is a cabinet that has the 20 consumer modules and 5 export routes each with appropriate milliammeters that indicate the flows passing through each compartment. Unit #4 is a control panel for the stand-up observer that provides for starting, stopping recording, and some changing of the inputs.

# Fig 1. Model and Exhibit

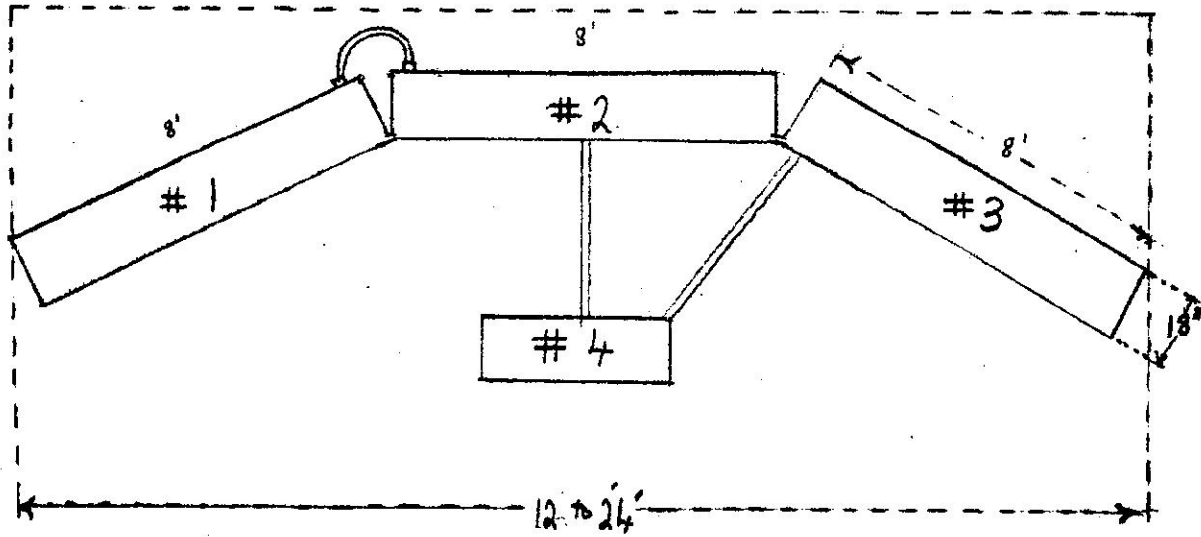
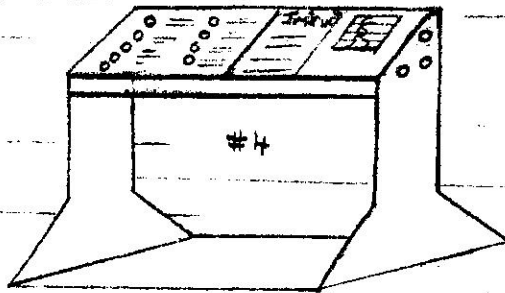
Explanations

Program-Inputs

Consumer Matrix

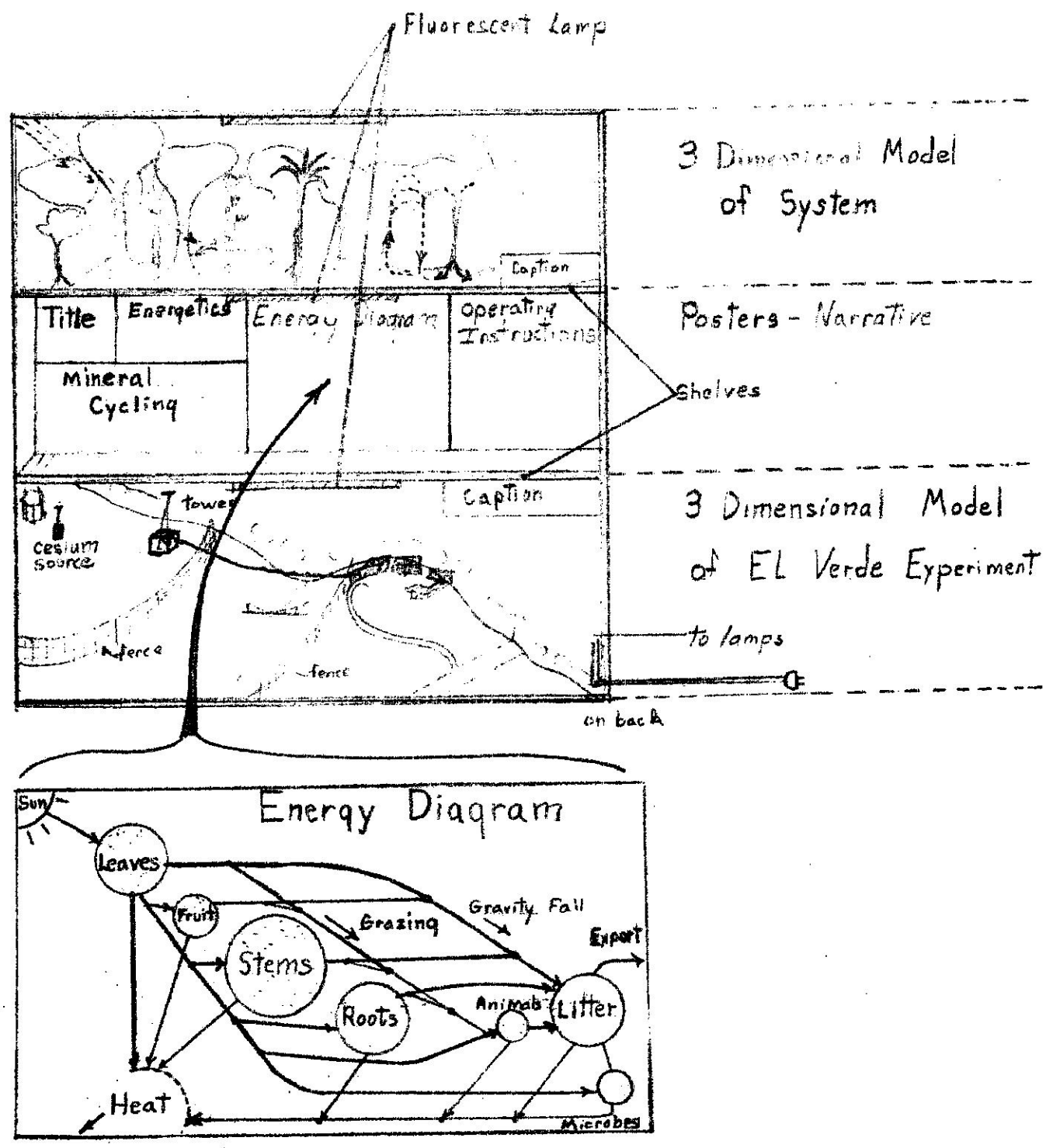


Front View



Top View

# Fig. 2. Explanatory Cabinet, Unit #1



The exhibit model provides for the 4 units to be arranged as shown in the inset of Fig. 1, the cabinets being protected by sliding plexiglass doors. The exhibit model includes a program of solar insolation that matches the real one plus a special program for the sequence of events due to high intensity gamma irradiation followed by recovery.

The exhibit units are self-contained and may be installed by plugging in power cables and interconnecting cables among units. Cabinets have wood front covers for protection during shipment.

The research model omits the explanatory cabinet #1. Plexiglass doors are also omitted in the research model since continual access to plug in modules is required. The explanatory cabinet is sketched in Fig. 2.

#### Unit #1 the Explanatory Cabinet

There are three parts of the explanation for the observer each separated by a shelf. The top shelf has a three dimensional model of the trees and other components of the rain forest to show the compartments of energy flow. The second shelf has some general posters about the exhibit on the Rain Forest project, and the means for operation by the visitor. The third section at the bottom has a three dimensional model of the El Verde situation, radiation source, instrument areas, towers, etc. The 3 dimensional model of the forest shows trees in a real pattern, litter, buttress roots, lianas, bromeliads, and some animals. These items will be done in wood, paper maché, plastic, and whatever may be necessary to portray the structural aspect. The compartments of the electrical model will be identified by a letter-number code and some of the principal routes of energy drawn with colored wires with arrows attached. The large plastic cylinder will be shown also. The three dimensional spatial model may have a caption thus:

"Three dimensional model of an area of montane rain forest at El Verde, Puerto Rico, site of experiments on the effects of radiation on the forest. Note the flow of energy of sunlight indicated by yellow wires entering from the left producing food in the leaves of the plants. The flow of food from the plants to animals and micro-organisms are indicated by the red wires. Each wire in this three dimensional model corresponds to a circuit in the electrical model in cabinet #2 and #3 to the right. Each of these flows of food energy is called a compartment and is found on the panels of the electrical model where the rates of flow are indicated by meters."

The middle section of the first cabinet has the following explanatory posters:

### "ENERGETICS OF ECOLOGICAL SYSTEMS"

"Hundreds of species of animals and plants living in stable inter-relationships constitute one of the world's most complex systems, the rain forest. The energy of the sun is divided among plant divisions, and thence via food chains the organic products of photosynthesis are routed to the various animals, non-green plant divisions, and micro-organisms. Some energy emerges as heat at each step as shown in the summarizing diagram (Fig. 2.). The energy thrust through each of the channels of plant photosynthesis is indicated by the voltmeters with green borders in Cabinet #2. Also emerging are the bound minerals that are released back to the environment as wastes from the various consumers."

(Fig. 2 shows the diagram to go on a poster with the above explanation)

### "CYCLING OF RADIOACTIVE ELEMENTS"

"Radioactive elements that may enter a rain forest as fallout or as a by-product of atomic excavation of a canal through a rain forest region, cycle through the plants and animals under the influence of the energy flows. The circuits of food flow are thus part of the flow of the radioactive elements, both being modeled by the electric model in the second and third cabinet.

In each compartment of cabinet 2 the yellow-bordered meter indicates the food chain input, and the red-bordered meter indicates the rate of respiratory regeneration of mineral elements including fallout."

### "INSTRUCTIONS TO VISITOR FOR OPERATING MODEL"

"Using the first switch turn on the input program of sunlight and observe the rotation of the large disc. The actual program of daily and annual light has been provided along the edge as teeth-like openings. Watch the flows and pulses of energy through the 20 consumer pathways by observing the meters in each compartment. Note that much of the daily pulse is dampened out after it leaves the plants.

After a fairly stable operation has been attained, cut off the sunlight by releasing your finger, and observe what happens to the metabolism of the various forest components. How long would they last without the energy input? Recall that the time for one complete rotation of the large disc is scaled as one year.

Turn on the original program of sunlight by pressing button again. After the system is operating for several turns, also press the button for intense radiation exposure to the forest representing an atomic explosion or heavy fallout. This button first eliminates all the plant surface. Then one plant species repopulates the area along with the animal chains that are dependent. Finally the system returns to normal as other components return."

Also given in Cabinet #1 is the electrical circuit for the whole model. The lower section of the first exhibit cabinet is a three dimensional view of the El Verde site on a different scale showing the actual topography, the radiation source, the instrument towers, some trails, the protective fence, the station, etc.. This will be accompanied by three colored aerial photographs. This model can be made of paper maché painted green with pertinent construction indicated in colored cardboard.

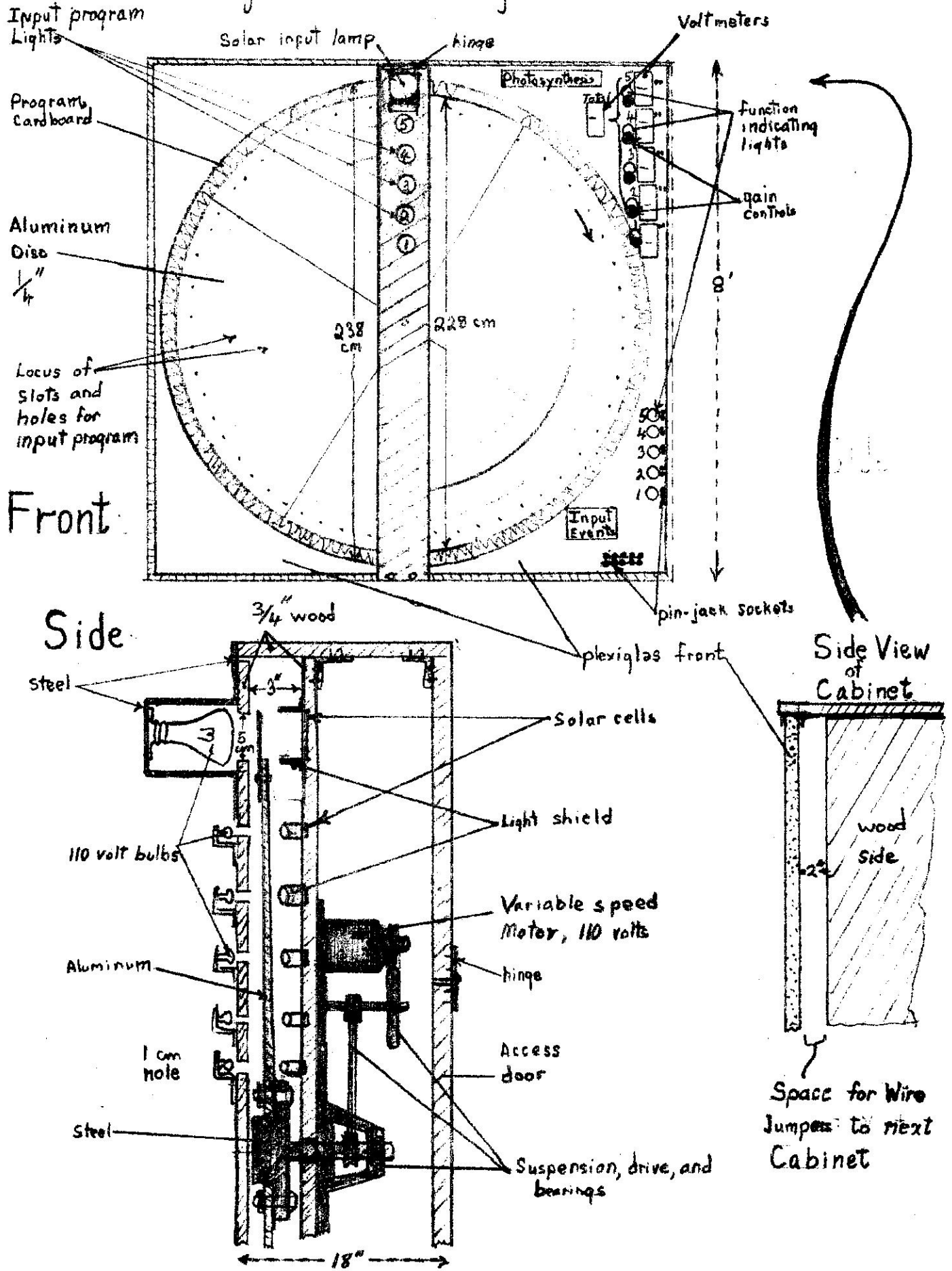
The visitor completing his study of the first cabinet should form visual images of the rain forest as a system of food circuits, and the El Verde project as an experiment testing radiation effects within this forest. He should understand that the other units of the exhibit show the network of flows of energy and minerals that follow from the pulsing input of light energy and other influences. He is ready to examine cabinet #2.

#### Unit #2 The Program Cabinet

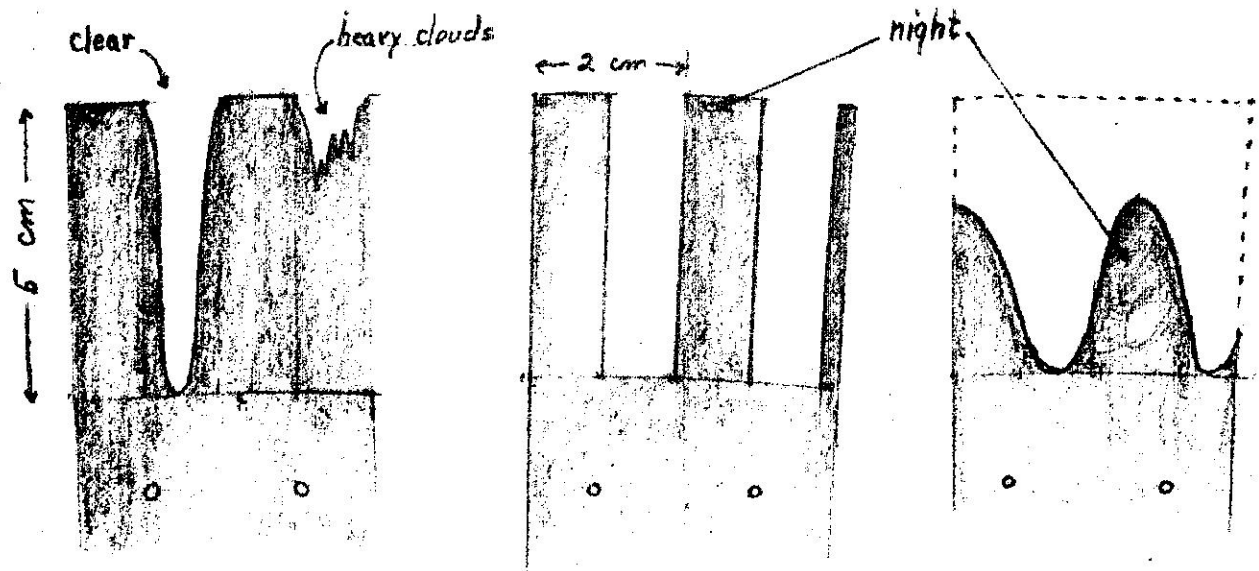
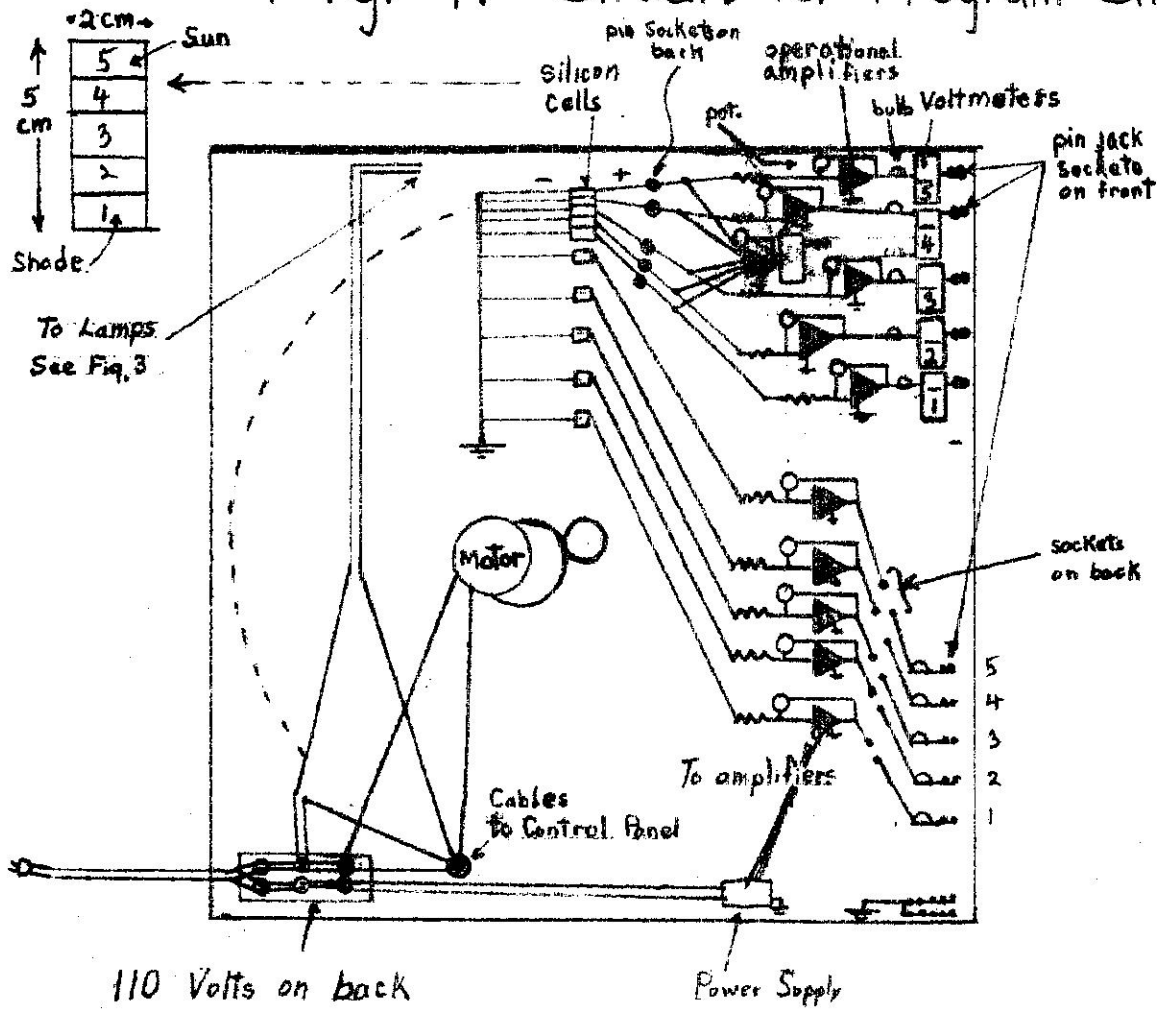
Details of the program disc and accessories are given in Fig. 3. A disc of aluminum rotates under variable speed control so that the period of input and storage may be scaled. The outer perimeter which controls the main input of light is fastened to the perimeter and may be changed to provide different sequences of day and night as shown in Fig. 3. Light in the ecological system is represented by a floodlamp located in the vertical bar over the disc. The light passing through the program of openings in the edge of the disc falls upon 5 silicon photocells that represent 5 plant compartments. The disc is rotated by a motor which may be varied in speed from the control panel so that the time scale of the input can be changed. Although storage capacities in the circuit are fixed, changing the rate of rotation permits the operator to vary the relative time constants as though one were varying the storage capacities, and one may scale the program to the real one more easily.

The program disc has 365 day sections each 2 cm long. These may be actual records of energy input observed in pyrhelimetric records or may be special hypotheses as suggested by the square wave in Fig. 4 .

# Fig. 3 Program Unit #2



# Fig. 4. Circuit for Program Unit #2



Observed Rain Forest      Square Wave      Arctic Summer

Sample programs



The vertical bar hinges up for access to the disc. The bar also has 5 smaller lights that work 5 other program inputs through holes and slots as may be cut in the aluminum disc.

Because photocells and photosynthesis both involve reception of photons on receptors regenerated for reuse by a cycling flow of limited quantity, both follow rectangular hyperbolas in response to increasing light intensity.

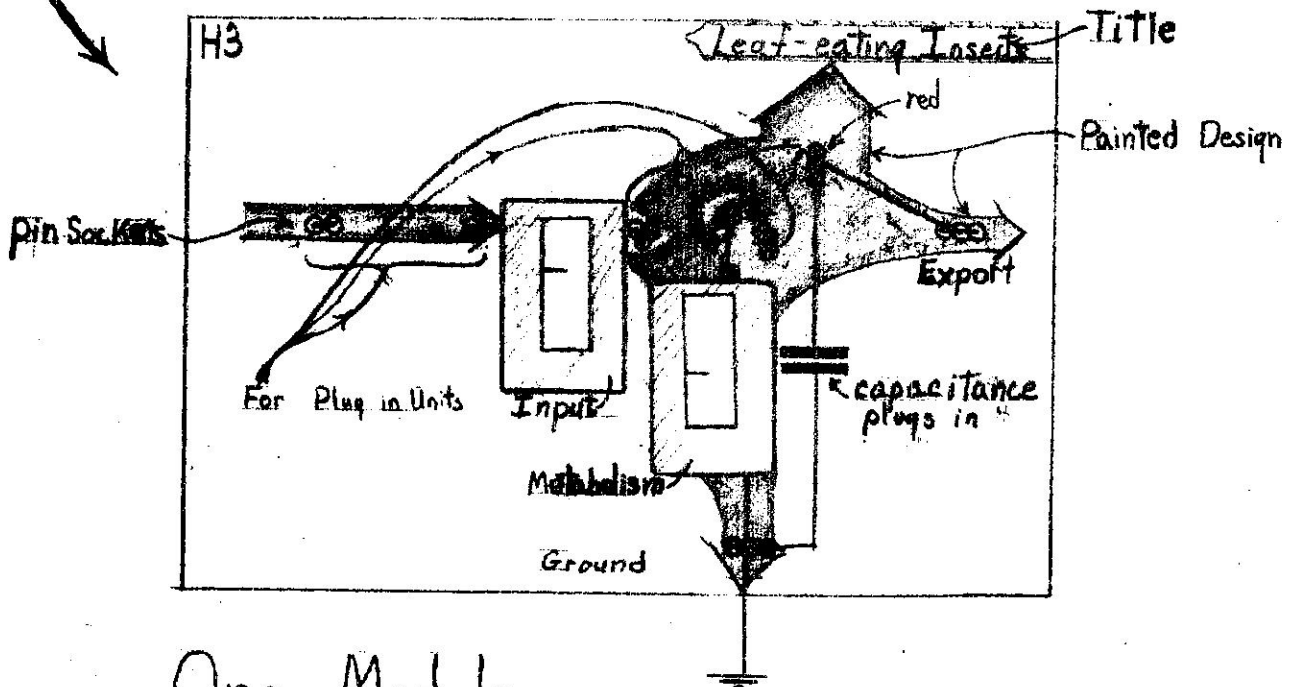
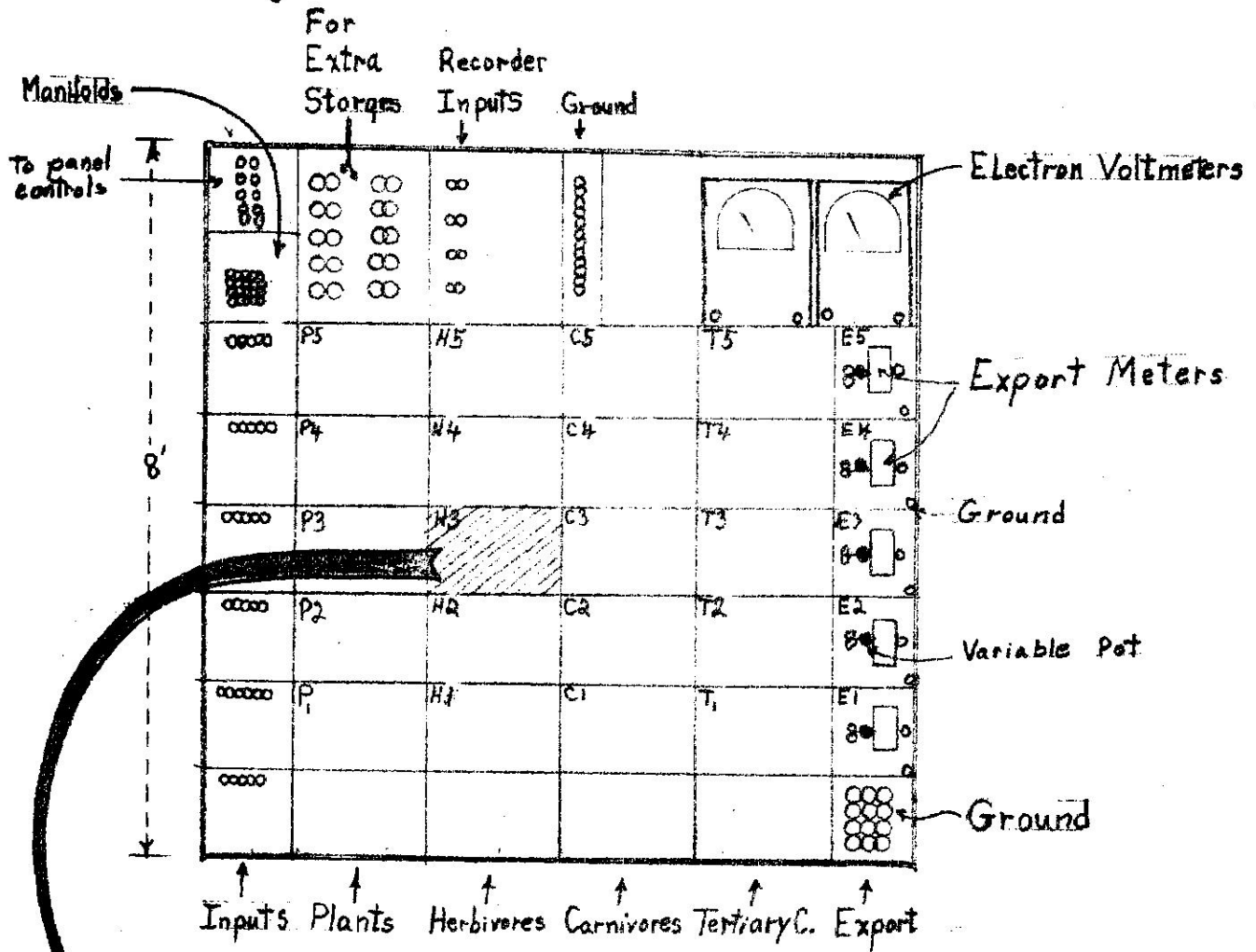
Hence the silicon cell is used to simulate the photosynthetic process. The curve of response when there is a substantial resistance load is as shown in Fig. 4. Since floodlamps have 91% infra-red radiation, the silicon cell is better than the selenium cell, since it includes more response in the infra-red, has less temperature dependency, and has higher output per photon.

The light passing through the program disk falls on the silicon cells each of which represents a separate compartment of photosynthetic entities. Such compartments can be species populations or they may represent separation according to sun and shade stratification. In the model described here 5 numbered compartments (silicon cells) are given. For experimental purposes these may be shielded or filtered separately. The output from each cell passes through an amplifier with a variable gain so that the millivolt output of the solar cells becomes voltage outputs for input purposes down-circuit.

The electrical output of each of these outputs representing primary photosynthesis leads to a pin-socket jack so that the outputs may either be combined or cross-linked in various ways. Each voltage is metered including the sum of the group read after passage through a summing amplifier so that no current is drawn from the network by the measurement. The sum represents the total primary gross production of ecologist's terminology. It is the chemical energy fixed prior to the drains of the plant's own maintenance and respiratory work processes. Man often asks how much is the total photosynthesis and how it is varying, but the separate circuits of the ecological system start with one photosynthetic population and may go separately and well insulated.

The large program disc used for solar input is also designed to program other events, again using the input of a lamp through holes and slots in the program disc followed by an amplifier as shown in Fig. 3. For example, if there should be immigration of a population at sometime of the year, the light through the slots opens a relay to activate the circuit. Such a relay operating down circuit may be plugged into the output of the special photocells provided at different radii. Five such special event controls are given. Pin jacks allow flexibility in these connections as shown in Fig. 3

# Fig. 5 Consumer Matrix Unit #3



One Module

As part of the exhibit, effects of intense gamma irradiation are simulated with these special event programs. One cuts off production for a period and then resumes it. Another routes all photosynthesis into one storage unit so that when production resumes, low diversity is simulated. A third provides emigration to reintroduce several species first eliminated.

The observer examining the program cabinet should visualize the kind of complex inputs to which natural systems are adapted and later, as he operates the model, observe the thrusts of photosynthetic energy by the meter indications and the small green lights on each of these input channels. In the research model, many of the experiments start with modifications of the input program, by adding or changing slots and perimeter serrations. From the input cabinet, the observer turns to his right to the third unit, the matrix of consumer circuits.

#### Unit #3 the Consumer Matrix Cabinet

In cabinet #3 are a group of repeating modules, 20 of which are the consumer population circuit compartments like that in Fig. 5 and 5 are routes for export. For convenience in interconnecting units pin jack sockets are provided with a common lead as labeled manifold. There are two sets of inputs to the recorder found in control unit 4. Also available along the top are one or more electron voltmeters whose input jacks may be plugged into the red storage sockets in the various compartments to indicate the condenser storages of organic matter in various populations. The 20 population compartments may be arranged to represent the various divisions of consumers including the respiratory systems of the plants involved. For the exhibit the vertical row on the left is for plant respiration, the second column of 5 for herbivores, the third column of 5 for carnivores, and the fourth column of 5 for tertiary consumers, especially micro-organisms.

As shown in Fig. 5, each population unit has an input flow that passes through several jumpers so that there is flexibility to permit plug-in components (diodes, interpopulations, extinction relays, logistic feedback, etc.). The inflow then reaches the storage unit from which are provided outlets for consumers, feedbacks such as for logistic growth, emigration, and immigration, and various other exports. The upper of the two milliammeters indicates the input flow.

A necessary feature of each population unit is the respiratory work and maintenance circuit which automatically drains energy into heat through a resistor representing the necessary aspects of self maintenance. This drain has a place for special features to be interconnected such as the extinction relay; or if nothing special

is desired, a jumper may be added. Such flow is monitored by the small meters (marked with red borders), since respiration is a measurable and biologically significant parameter. It measures the rate of mineralization and release of chemical elements including many radioactive elements that might have been bound in that population flow.

All flows of organic carbon and hence of chemical potential energy are automatically portrayed by ammeters. For economy reasons the small panel meters of Guilton Co. are suggested. The rapid switching of dozens of small meters during the program of energy flow through a diurnal and annual program is an impressive demonstration of the working of the ecological system that is exciting to a specialist or to the citizen with casual interest. That forests and seas are flushing and switching in this way invisibly before us is realized in most programs of education. Meters are properly labeled, given a colored border, and provided with a pair of pin-jacks for amperometric recording should it be desired.

Storage of organic matter and with it chemical potential energy and the ability to drive other ecological circuits occurs in living populations and in some dead storages such as the leaf litter of the forest floor or the interior of some trees. Any storage is represented in the passive analog model by a condensor of large capacitance where capacitance is in proportion to the weight of that quantity of organic matter when it reaches its fullest development under a given input thrust. See Table 1.

The first storage units represent the matter within the photosynthetic units, the leaves, as shown in Fig. 2. The charge on any storage unit can be followed at any time by plugging in the electron voltmeter jack or by plugging in a recorder jack. For the model being constructed capacitances are largest in the upper left compartment and decrease downward and to the left. Auxiliary storages may be inserted from the section in the top row.

Almost all of the food chains in ecological systems involve work expended crossing energy barriers so that they are not reversible. They are one way valves and require a diode. Diodes may be inserted by pin jacks in the input of each circuit. See Fig. 5.

For many more sophisticated representations an extinction relay must be plugged into the input circuit of each population so that if the maintenance respiration circuit becomes less than the minimum necessary to support the minimum population possible, the relay held closed will open, taking that compartment out of the system. Thereafter it can be reestablished only by an emigration circuit to the storage as provided from the program disk. Where extinction and emigration are not to be considered, simple jumper wires are used in place of the extinction relay.

Whereas the asymptotic charging curve of a condenser has been shown to be a realistic model for storage of compartments of leaves and some animal and plant growth, it is not a good model where the input is increased in proportion to the storage, as when a growing population reproduces so as to cause more input of food from more mouths or more area of leaves for more light to fall. For such populations a plug-in module for logistic feedback is required. Here the conductance of the input across one pair of jack positions to a population is increased in proportion to the voltage developing on the storage downstream. This is the logistic feedback and is provided by a servomechanism which provides a change of conductance in one circuit due to the voltage of a second. For the present model, a raysister may be satisfactory, or some other unit may be tried. The logistic feedback units may be added as considered appropriate or left off and replaced with a simple jumper wire. If one is portraying the inputs and outputs of energy of a forest system not far from a steady state so that the number of photosynthetic units and animals is held fairly uniform, the feedback is not applicable, but if one is starting from zero initial population, the feedback may be appropriate.

Most of the functional units are added as plug-in jumpers across pin jacks which are labeled for identification. This system provides maximum flexibility for research purposes, maximum ease of maintenance, minimum cost for initial construction, omission of some units at first, and yet allows the system to be used as an exhibit model. Where the exhibit model is desired, a plexiglass overlay is provided in front on the main panel to keep visitors from changing the plug-in units and to allow the visitors to see the parts.

This passive network for the ecosystem resembles somewhat other kinds of analog computers in appearance, although operational amplifiers are mainly absent, flowmeters are more abundant, and both voltage and amperage are observed for significance.

To help the visitor interpret the significance of the input flow, storage, metabolic flow, and exports from each compartment, a painted image of a mouth and tank is provided for each consumer unit as shown in Fig. 5. Having examined the nature of the third cabinet with its visual image of many hungry mouths leading to storage tanks, the visitor can turn to the control panel and put the model through several operations.

#### Unit #4 the Control Panel

As given in Fig. 1 the control panel is mounted on a 45 degree angle for the stand-up observer and located in front of the #2 cabinet. It is mounted on a stand which folds for shipping. Part of the panel is a dual channel strip chart recorder whose input jacks are located in the top row of cabinet #3.

The exhibit model has very simple controls as follows:

1. On and off button for the main program wheel; positive pressure is required to keep the wheel going in the exhibit model.
2. Control for varying the wheel speed.
3. Start button for the modifying radiation simulation.
4. Start of the strip chart recorder, with automatic spring stop when hand is released.
5. Push buttons to disconnect column 1, 2, 3, 4 or 5 of the consumer model.

The strip chart recorder must have a wide range of pre-amp controls so as to permit its use for various compartments, but these controls will be covered by a wood panel in the exhibit model.

For the research model, the buttons are replaced with on-off switches that hold circuits closed without finger pressure. Also provided in the research model are 5 toggle switches on the control board that close the circuits between the pairs of pin-jacks marked "switches" in the program cabinet. These allow various plug-in arrangements to be controlled from the control panel.

The visitor who comes to the exhibit may make some simple operations according to the written instructions.

- "1. Turn on the program of light and watch the storages charge representing the energizing of all the community parts.
2. Interrupt the light program and watch what would happen if sunlight were interrupted.
3. Pull a switch that removes plant consumers, carnivores, herbivores, or bacteria, and observe the effects.
4. Follow the action of radiation in eliminating the system's function, followed by recovery including diversification; observe recharging storages and metabolism in the various components.
5. Vary the relative time scale of the system and inputs so as to get varying stability of component storages."

### Plug-in Units

In addition to the 4 main units and their contained circuits, a number of plug-in units are required to set up either research or exhibit programs. A partial list is given in Table 2. At the bottom of that table are those units which are only now being tested. Although their action is clear, the exact designation in terms to permit immediate order has not been made pending some further exploration. The performance criteria of these parts are included in the table and it may be that the group constructing this model may have some definite recommendation of plug-in devices to accomplish these criteria. The construction of the model may be made first so that several units may be tried in the completed circuit.

Also part of the model are multi-conductor cables and screw-in attachments for joining the 4 units together. They are included in Table 2.

TABLE 2

Partial List of Plug-in Components, all fitted with pin jack plugs.

- 1 Dual Channel Strip Chart Recorder; these are sockets for more
- 1 Electron Voltmeter with biomass scale overlay (cabinet has space for 3).
- 100 double pin jumpers;
  - 40 - 15" long
  - 10 - 6" "
  - 50 - 8" "
- 30 double pin jumpers with diodes.
- Cable from control panel #4 to cabinet #3  
(5 to control sockets, 4 for recorder sockets) with 9 pairs of wires.
- Cable from control panel #4 to cabinet #2 with a 110 volt power extension and 5 pairs of wires to input program.
- 25 plug-in capacitors.

Plug-in Modules Requiring choice of means:

- 10 Extinction relays. Flow in one circuit below 10 milliamperes opens second circuit.
- 10 Logistic feedbacks. Conductivity in one circuit is lowered linearly with rise of voltage in a second 0 to 100 volts with conductivity varying.
- 1 Timing circuit, which opens and closes circuits plugged into sockets for control on cabinet 2. At push button start, 4 circuits are opened and then are closed successively at intervals of two minutes.
- 5 Program relays for cabinet 2; 10 volts closes a second circuit and holds it until the voltage disappears.

### Final Programming of the Exhibit

Once the model is built as outlined in this prospectus, the exhibit model may be programmed using rain forest data on input radiation and relative sizes of storages. After some trial and study with plug-in modules, the final circuit can be put on paper so that it may be readily restored if dis-assembled during shipping. This final phase can best be done by the personnel of the rain forest project, whereas the basic units may be constructed by others.

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