FUNDAMENTALS OF PHOTOVOLTAICS FOR THE FIRE SERVICE

TOPIC: 2: Photovoltaic Cells and Components

TIME FRAME: 2:00

LEVEL OF INSTRUCTION: Level 1

BEHAVIORAL OBJECTIVE:

Condition: Given a written test

Behavior: The student will confirm their knowledge of photovoltaic cells and components by completing the written test.

Standard: With a minimum 80% accuracy according to the information contained in:

- <u>Fundamentals of Photovoltaics for the Fire Service</u>, Rodney Slaughter, September 2006

MATERIALS NEEDED:

- Writing board or pad with markers/erasers
- Appropriate audiovisual equipment
- Appropriate audiovisual materials

REFERENCES:

- <u>Fundamentals of Photovoltaics for the Fire Service</u>, Rodney Slaughter, September 2006

PREPARATION: In this section we are going to discuss how a photovoltaic cell works, what it is made of, and the other components essential to the operation of the system. Understanding how the system operates is the key to working around PV systems safely. We will also discuss other solar technologies like skylights and solar water heaters as they relate to emergency response.

PRESENTATION	APPLICATION
	Slide 1 - Agenda “PV Components”
I. OBJECTIVE	Slide 2 – Behavioral Objective
A. At the end of this section you will be able to identify and describe the operation of a photovoltaic system	
	Slide 3 – Solar Facts
II. SOLAR FACTS	
A. In a single sunny day enough sun falls on Earth to supply all the worlds energy needs for four to five years	
B. The sun’s full intensity and brightness is 1,000 watts per meter squared, referred to as insolation	
C. Specific conditions like shading, clouds, smog, can diminish the PV output	
	Slide 4 – Solar Facts
D. In the northern hemisphere most PV systems are oriented towards true south	
E. Peak sun is about 5 hours per day between 10 am and 3 pm	

PRESENTATION	APPLICATION
	Slide 5 – Solar Cell Anatomy
III. SOLAR CELL ANATOMY	
A. The PV solar cell is the smallest unit of the system	
B. Two types of manufactured PV: 1. Silicon cell 2. Amorphous silicon	
C. In either case a thin film of silicon is used, 1/100th of an inch thick	
D. Silicon is one of the most abundant elements on the planet	
E. This is the same silicon in quality and purity as that used in the semiconductor industry	
	Slide 6 – Solar Cell Anatomy
F. Manufacturers layer slices of silicon with atoms of boron or phosphorus in a process known as doping	
G. Boron is used for the positive layer of the cell in that Boron has a hole in the outer shell of the atom to add an electron	
H. Phosphorus, has an extra electron and is used for the negative layer of the solar cell	

PRESENTATION	APPLICATION
	Slide 7 – Solar Cell Anatomy Graphic
I. The physics of PV 1. Photons generated from the sun energize and knock loose the extra electron in the negative layer, crossing the positive-negative (P-N) junction to fill the hole on the positive Boron side 2. The energy released in the process produces .5 volt of direct current (DC) and flows through the metal contacts built onto the cell 3. Energized electrons flow through the circuitry of the wiring system, run the appliances, and then flow back into the negative layer to be re-energized	
	Overhead Question- The process just described is similar to what other technology? **Answer-** Battery technology Slide 8 – Manufacturing
IV. MANUFACTURING PROCESSES A. The composition of the silicon crystalline structure varies from manufacturer to manufacturer	

PRESENTATION	APPLICATION

B. The purest silicon structure employs the growth of a single crystal (monocrystalline) cut in to thin wafers

C. Multiple crystals cast together and sliced into thin wafers form polycrystalline structures

D. Other manufacturers use a chemical process which deposits silicon on a substrate material

   1. These panels don’t have the circles because the entire surface of the substrate is the “cell”

   2. Silicon deposited on glass or stainless steel as a thin film is referred to as amorphous

Slide 9 –Manufacturing

E. To improve PV efficiency and reduce cost, the industry is using other materials such as cadmium telluride and gallium arsenide

   1. The industry is also developing synthetic alternatives to the silicon wafers

   2. Toxic and hazardous chemicals are used in the PV manufacturing process

PRESENTATION	APPLICATION
3. When a module is exposed to fire or an explosion, trace chemicals can be released into the atmosphere	
4. The inhalation of PV modules fumes and smoke "could affect human health"	
5. The concentration of PV modules in commercial applications (larger PV arrays), the risk would be higher for surrounding populations than for PV systems on residential fires	
F. Monocrystalline	Slide 10 – Monocrystalline
1. the oldest and most expensive production technique	
2. Complete modules have output capacities of 14 to 15%	
3. Boules (large cylinders) of pure single-crystal silicon are grown in an oven, and then sliced into semi-circular wafers before being doped and assembled	
4. Monocrystalline achieves the highest efficiency in electric energy production and its production cost is higher than other silicon types	

PRESENTATION	APPLICATION
	Slide 11 – Polycrystalline
G. Polycrystalline 1. In this production technique, pure molten silicon is cast into molds, then sliced into wafers, doped and assembled 2. Polycrystalline is lower in conversion efficiency compared to Monocrystalline, averaging about 12 to 14% output capacity 3. Polycrystalline is shaped as a square, taking in as much of the available area of the PV module as possible	
	Slide 12 – Amorphous
H. Amorphous 1. Amorphous silicon is made by vaporizing silicon and depositing it on a glass or flexible surface 2. Some amorphous PV panels are flexible and are able to be rolled and used for remote electricity generation 3. Strips of amorphous PV can be wired together to form an array	

PRESENTATION	APPLICATION
4. Thin film (amorphous) PV products can be laid between the seams of metal roofs and held into place with an adhesive backing	
5. Other thin film panels are made on a rigid substrate so that they can be installed in the same manner as the other types of PV panels	
6. The flexibility of amorphous technology allows it to be used in a wider range of applications	
	Slide 13 – Amorphous Application
a) This picture shows amorphous technology used in a glass canopy over a BP gas station in Fairfield, CA	
b) Looking up through the canopy, the small grids that channel electrical energy to the distribution conductors	
	Slide 14 – Amorphous
7. The production technique costs less than other production techniques, but the output capacity, is reduced to 5 to 7%	
8. A square foot of amorphous silicon averages about 5 watts, crystalline averages about 10 watts per square foot	

PRESENTATION	APPLICATION
	Slide 15 – Photovoltaic System
V. PV SYSTEM A. Consists of: 1. Modules/Array (Tiles & Shingles) 2. Optional Batteries 3. Battery Controller 4. Inverter 5. Mounting Systems	
	Slide 16 – PV Modules
B. Photovoltaic Modules 1. Solar cells are covered with an antireflective material, on a backing material, encapsulated within a glass and aluminum frame 2. Several cells connected together in series and parallel the voltage and amperage is accumulated to achieve the desired electrical output 3. Photovoltaic cells connected together in this manner form a PV module 4. Weather-proof electrical connections on the back of the module to connect to other modules that comprise the PV array	

PRESENTATION	APPLICATION
5. In rare occasions junction boxes can overheat and can lead to roof damage and potential fire	
	Slide 17 – PV Modules
6. Modules have a variety of sizes and rated output, with the standard size module at 24-volts, consisting of 72 solar cells	
7. An average size crystalline module weighs between 30 and 35 pounds.	
8. Photovoltaic panels have no moving parts, require little maintenance.	
a) A building owner will occasionally hose and/or squeegee dust, dirt and bird droppings to keep the array operating at peak efficiency	
9. The panels themselves are completely weather proof, so there is little danger to the building occupants who perform this maintenance function	
	Slide 18 – PV Array
Photovoltaic Array	
10. Two or more modules connected together form a photovoltaic array	

PRESENTATION	APPLICATION
11. Modules are wired together in a series to accumulate voltage, and the strings are wired in parallel to increase amperage 12. Residential system outputs of 600 volts are not uncommon	
13. The average household in California uses about 6,500 kilowatt-hours per year	Slide 19 – PV Array Graphic
14. This graphic shows the wiring scheme in series and parallel for a single array	Slide 20 – PV Array
15. A PV system in the 3 to 4 kilowatt range would meet most homeowner’s electricity needs	
16. A 30 module array would operate at over 4,000 watts and weigh approximately 900 to 1,050 pounds	
17. This weight would be spread equally over a 420 square foot area of the roof, resulting in a roof weight load of approximately 2.5 pounds per square foot	Overhead Question: Are there other ways to put PV on the roof? Answer: Yes! Solar tiles and shingles

PRESENTATION	APPLICATION
	Slide 21 – PV Tiles and Shingles
C. Photovoltaic Tiles and Shingles 1. PV tiles or shingles can be integrated into the home's roof covering, becoming part of the structure 2. This is a form of "building-integrated" design. 3. PV roof tiles and shingles duplicate the depth of cement or clay tile roofs or composition shingles 4. It takes more time, wiring and bundling individual tiles or shingles together 5. PV tile or shingle roofing system is less obtrusive but costs more than mounting modules and arrays 6. In high fire hazard severity zones, roofing systems must meet Title 24 of the California Building Code for Class A roofing materials 7. Building integrated PV tiles or shingles would also have to meet this regulation	
	Slide 22 – Roof Tile Photo

PRESENTATION	APPLICATION
8. Manufacturers of PV roofing tiles have tested their products and have met the standard for Class A roofing 9. Manufacturers of PV shingles have achieved a Class A rating by using a fire resistant underlayment beneath the PV shingles 10. PV modules that are mounted on racks above the roof covering would not have to meet the roofing requirement—but the roofing material underneath would	
D. Battery Systems 1. Lead acid batteries are used to store solar-generated electricity a) Batteries are used in off-grid PV systems, although battery back-up can be used in grid-connected applications b) Without batteries, a PV system cannot provide electricity when the electrical grid is not energized	Slide 23 – Batteries
	Slide 24 – Off Grid System Photo

PRESENTATION	APPLICATION
2. Pinnacles National Monument in California installed a 9.6-kilowatt photovoltaic system. It eliminates the fuel bill for a diesel generator that produced 143 tons of carbon	
a) Batteries are used to store the electricity generated during the day	Slide 25 – Batteries
3. A battery is an electrochemical cell in which an electrical potential (voltage) is generated at the battery terminals by a difference in potential between the positive and negative electrodes	
a) When an electrical load (appliance) is connected to the battery terminals an electrical circuit is completed	
4. A battery consists of five major components; electrodes, separators, terminals, electrolyte and a case or enclosure	
a) There are two terminals per battery, one negative and one positive	
b) The positive electrode of a lead acid battery consists of a lead grid covered with lead oxide (PbO_2)	

PRESENTATION	APPLICATION

c) The negative electrode is essentially lead (Pb) with an inert expander that causes the surface to be porous

d) The electrolyte is sulfuric acid (H_2SO_2) in a liquid form or can be immobilized in a glass mat or suspended in a gel

e) The electrical potential between the positive and negative electrodes is about 2 volts direct current (DC)

f) The voltage varies with temperature, the state of charge, and whether the cell is being charged or discharged

g) During discharge, the voltage decreases as the state of charge decreases

h) As the battery approaches a state of full discharge, the exchange of electrons from the positive and negative electrodes continues until both are covered with lead sulfate and are at equal electrical potential; referred to as a discharged cell

PRESENTATION	APPLICATION
i) During the charging process, the reactions occur in the opposite direction to reform both electrodes back to lead and lead oxide respectively j) As the reformation proceeds, the electrical potential of the cell is returned to its original value of approximately 2 volts k) Outside the battery, current flows from the positive terminal, through the appliance and returns to the negative terminal l) If the electrical load is replaced by an external power source that reverses the flow of the current through the battery, the battery can be charged m) This process is used to reform the electrodes to their original chemical state, or full charge 5. Battery Charging a) The battery can enter a state of over charge in which the electrodes will off-gas oxygen from the positive electrode and hydrogen from the negative electrode	

PRESENTATION	APPLICATION
b) In conventional, free flowing electrolyte batteries, the gasses bubble through the electrolyte to the surface and out of the battery, resulting in a drop in the batteries electrolyte level	
c) The escaping gases are highly flammable	
d) For this reason, sparks and open flames are not allowed in the area of the batteries	
	Slide 26 – PV Battery Bank Photo
6. Like the PV modules, batteries are wired in series and parallel to provide the voltage and amperage necessary for the operation of the system	
	Slide 27 - Controllers
E. Controllers	
1. To keep battery charge levels in check, a charge controller is used in the PV system	
2. The battery charge controller prevents over-charging reducing the danger of off-gassing	
3. Many controllers also protect the battery from over-discharges as well	

PRESENTATION	APPLICATION

Slide 28 – Controller Photo

4. Battery charge controllers are found in off-grid and grid-tied systems with battery back-up

5. A PV charge control senses battery voltage

6. When the batteries are fully charged, the control will stop or decrease the amount of current flowing from the PV array into the battery

7. When the batteries are being discharged to a low level, many of the controllers will shut off the current flowing from the battery to the DC loads

8. Charge controllers come in a variety of sizes, from a few amps to as much as 60 amps

Slide 29 – Inverters

F. Inverters

1. The PV array, batteries and charge controllers all function on direct current

2. Off-grid PV owners can also use direct current appliances

PRESENTATION	APPLICATION
3. DC appliances are more expensive, limited in variety, and harder to find than their alternating current counterparts	
4. To take advantage of a wider range of appliances, or to connect to the grid, the PV direct current has to be converted to alternating current	
	Slide 30 – Inverters Photo
5. This is accomplished with a PV inverter	
a) The inverter changes the direct current to alternating current at 60 hz	
b) Inverters are classified according to the waveform they produce	
	Slide 31 – Inverters
c) There are three types of inverters; square wave, modified square wave and sine wave	
d) Sine wave inverters produce a high quality waveform used to operate sensitive electrical equipment	
e) Utility connected inverters are required for grid-tied PV systems	

PRESENTATION	APPLICATION

f) Utility grid inverters are typically of the sine wave type in order to correspond to the frequency of the utility supplied power

g) Grid-tied inverters and are designed to shut down the solar generated electricity when there is no grid power

h) When converting DC to AC a significant amount of heat is generated

i) Inverters are designed with a heat sink assembly to dissipate the heat away from the system.

Slide 32 – Mounting System

G. Mounting Systems

1. There are a variety of ways that PV modules and arrays can be mounted

2. Typically a roof with a southern exposure allows a quick and effective installation.

3. There are systems that can be mounted directly on the roof, in many cases specialized roof racks lift the array from the roof deck allowing for air to circulate under the modules

PRESENTATION	APPLICATION
4. Many PV systems are designed to withstand 80 mile per hour winds.	Slide 33 – Mounting System
H. PV systems can also be mounted on the ground using customized racks, or they can be mounted on poles	
I. Tracking systems allow the entire array to move with the direction of the sun	Slide 34 – Solar Technologies
VI. Other Solar Technologies	
A. Solar thermal panels (solar water heating collectors), are used to heat water for the swimming pool or for domestic hot water	
1. Unlike PV panels, which convert up to 15 % of the suns energy into electricity, solar thermal panels convert 95% of the sun's energy into heat	
2. Another type of solar thermal panels is used exclusively for heating swimming pools	
3. These panels usually consist of a polymer material, and usually lay flat on the roof	
4. Solar pool heating panels usually have no glass cover plate or other metal enclosure	

PRESENTATION	APPLICATION

5. Solar thermal panels run copper tubing inside an aluminum box with a flat or convex glass cover

6. Solar thermal panels are not inherently dangerous to emergency responders-- unless fire fighters trip over them while working on the roof!

7. There is no wiring associated with solar thermal panels- only plumbing and hot water

8. It is important to be aware that both technologies can be in use on the same roof at the same time

B. Skylights are a function of passive solar design—allowing natural light to enter the interior of the building

1. When they are available, fire fighters can use skylights to ventilate the building of superheated gasses and smoke expeditiously

Slide 35 – Solar Technologies

2. Skylights from the interior of the structure, with a sheet rocked ceiling, will be sheet rocked up to the underside of the skylight

a) This is advantageous to fire

PRESENTATION	APPLICATION
fighters in that the chimney created by the sheet rock underneath the skylight also provides some protection from superheated gas and smoke getting into the attic area	

3. Another advantage is that a broken skylight is cheaper to fix than a hole chopped in the roof assembly

4. Skylights come in a variety of shapes and sizes and are fairly distinctive with clear, translucent or tinted plastic or glass

5. To keep rain from getting inside the skylight, they are integrated into the roof with metal flashing around the base

6. A skylight with integrated photovoltaic will have a distinctive amorphous rectangular pattern in the glass

7. It is conceivable that skylights may be on the same roof as PV panels and solar thermal panels

PRESENTATION	APPLICATION
	Slide 36 – PV - ID

VII. Photovoltaic Identification

A. PV panels are distinctive, making them relatively easy to recognize when you know what to look for

B. In the case of monocrystalline, the PV panel looks like there are a group of semi-circular squares that are laid out in a rectangular panel

C. Polycrystalline panels have square cells laid out in a rectangular panel

D. In either case these modules are usually laid on a racking system elevating them a couple of inches above the roof

E. Amorphous panels have a pattern of rectangles integrated across the entire panel

F. The color of all these solar cells ranges from black to blue

G. It is not recommended that fire fighting personnel attempt to remove or cut into the PV modules in case of an emergency

H. Attempts to do so could potentially release all the energy inherent in the system simultaneously

PRESENTATION	APPLICATION
I. Similarly, there is no need to cut into or remove a solar thermal module (water heating collector) during a structural emergency	
J. Skylights with integrated PV circuits should not be broken for ventilation purposes	
K. All other skylights can be used for ventilation purposes if it meets the strategic and tactical objective of the emergency	
L. When the PV array covers the south facing roof, and the need to ventilate occurs, choose a spot on the east, west or north facing slope of the roof and cut a ventilation hole at the highest point over the fire	
	Slide 37 – Summary
VIII. SUMMARY	
A. The greatest danger for emergency responders is the lack of PV knowledge needed to safely operate around this emerging technology	
B. This section provided you with an introduction to the photovoltaic system	
C. Identification of the PV array and all the related components is critical in an emergency response	