FUNDAMENTALS OF PHOTOVOLTAICS FOR THE FIRE SERVICE

TOPIC: 6: Emergency Response

TIME FRAME: 2:00

LEVEL OF INSTRUCTION: Level 1

BEHAVIORAL OBJECTIVE:

Condition: Given a written test

Behavior: The student will confirm their knowledge of potential PV hazards and be able to develop a standard operating guideline for their department.

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

- Fundamentals of Photovoltaics for the Fire Service, Rodney Slaughter, September 2006

MATERIALS NEEDED:

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

REFERENCES:

- Fundamentals of Photovoltaics for the Fire Service, Rodney Slaughter, September 2006

PREPARATION:

The days of rushing in to a structure without first making an assessment and size-up of the emergency have long past. We suggest that fire fighters need to be aware of photovoltaic technologies and the potential dangers and hazards. The potential dangers, in the form of an electrical shock and the potential hazards in the form of hazardous chemicals released during a fire or an explosion, along with trip hazards and load weight on the roof. This section will review these dangers and hazards as well as make recommendations on how you can personally protect yourself.

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PRESENTATION	APPLICATION
	Slide 1 - Agenda "Emergency Response"
I. OBJECTIVE	Slide 2 – Behavioral Objective
A. To identify and mitigate potential hazards from working around PV at the site of an emergency	
B. To use this information to develop a standard operating guideline for your department	Slide 3 – Fire Fighter Hazards
II. INHALATION HAZARDS	
A. Hazards associated with PV and roof operations include: 1. Inhalation Hazards 2. Shock Hazards 3. Falls from roof 4. Roof Collapse 5. Batteries	
B. We are going to not only review these hazards but also discuss: 1. How to you work around PV 2. What not to do around PV	Slide 4 – Inhalation Hazards
C. The manufacturing of silicon cells is very similar to the process used in the semi-conductor industry	

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PRESENTATION	APPLICATION
D. A wide range of hazardous chemicals are used in this manufacturing process	
E. By the time the solar module is ready for installation, only a few of these chemicals exist in the finished product, in minute quantities, and they are sealed in the module frame and coverings	
F. During a fire or explosion the frame can quickly degrade exposing these chemicals to direct flame and become dissipated in the smoke plume	
G. When you review and compare the list of known chemicals you realize how serious some of these chemicals are to human health:	Slide 5 – Inhalation Hazards
H. Boron 1. Of all the chemicals used in photovoltaic manufacture, Boron is the least problematic for emergency responders and the public alike 2. Boron is one of the simplest of atoms with an atomic number of 5 on the element chart	

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PRESENTATION	APPLICATION
3. There are only four elements simpler than boron 4. Boron hydrolyzes in water to form a slightly alkaline solution, which is why Boron is good for cleaning (Borax Soap) 5. Boron burns green and is used in pyrotechnics for color 6. Boron poses no health effects to humans or the environment I. Cadmium Telluride 1. The same, however, cannot be said for Cadmium Telluride 2. A known carcinogen, the primary route of exposure is inhalation 3. Dust and fumes from cadmium or its compounds may cause irritation of the nose and throat 4. If high concentrations are inhaled (especially from a freshly formed plume) a delayed reaction of coughing, chest pain, sweating, chills, shortness of breath and weakness may develop 5. In severe cases of exposure the result can be pulmonary edema and death	

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PRESENTATION	APPLICATION
6. Acute exposure to tellurium may cause an odor of garlic on breath and perspiration, dry mouth, metallic taste, sleepiness, loss of appetite and nausea 7. Chronic overexposure may cause lung injury (emphysema) and kidney dysfunction (proteinuria) 8. Inhalation of cadmium telluride will aggravate diseases of the lungs and kidneys 9. With that said, the Photovoltic system contains trace amounts of these elements per cell 10. The potential exposure hazard to a small residential array will be minimal 11. Larger arrays, like those found in large commercial applications, fully engulfed in a roof fire could be a potential exposure hazard to emergency responders and the population down wind of the smoke plume 12. Citizens with respiratory ailments, children, and the elderly should be sheltered in place until the emergency has been abated	

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PRESENTATION	APPLICATION
J. Gallium Arsenide 1. The health effects of Gallium Arsenide have not been thoroughly studied 2. It is however, considered highly toxic and carcinogenic 3. Gallium rivals silicon as a semiconductor in that it too has some remarkable electronic properties 4. However, silicon is much more abundant, and therefore less expensive, and it has greater physical strength than gallium. 5. Gallium Arsenide, when combined with germanium and indium gallium phosphide, are the basis of a triple junction solar cell which holds the record efficiency of over 32% 6. This is the same solar technology that is powering the robots Sprit and Opportunity which are exploring the surface of Mars and is being used in experimental solar cars here on Earth K. Phosphorus 1. The fumes from phosphorus compounds are considered highly toxic	

PRESENTATION	APPLICATION
2. NIOSH recommended exposure limit to phosphorus is 5 mg/m3 3. A lethal dose of phosphorus is 50 milligrams 4. Phosphorus is extremely important to the agricultural industry as a primary ingredient in the production of fertilizer 5. Pure white phosphorus is extremely volatile and spontaneously ignites when exposed to the air 6. The type of phosphorus used as a dopant in the manufacture of photovoltaic cells is not in its pure form, but any form of phosphorus will react to extreme heat 7. Respiratory protection is required for people working around phosphorus	Slide 6 – Inhalation Hazards
L. Recommended Practice 1. The inhalation hazards from the chemicals inherent in PV modules engulfed in a fire or explosion can be mitigated with SCBA's and personal protective equipment during a structural firefighting operation	

PRESENTATION	APPLICATION
2. It is the decision of the Incident Commander whether or not the emergency constitutes sheltering in place the population downwind of the emergency 3. Fire or explosion emergencies involving large number of PV arrays, as in a commercial application, may necessitate having people downwind of the emergency shelter in place	
	Slide 7 – Electrical Hazards
III. Firefighter Electrical Safety A. The primary danger for firefighters working around an electrical system, and specifically PV systems, is electrical shock B. The problem most firefighters have with electricity is that they cannot see it coming C. Unlike a fire, which produces flames and heat, and burns in a relatively predictable manner, electricity, when it is not given its due respect, can strike unsuspecting victims—sometimes fatally! D. A review of NIOSH reports reveal that many electricians and utility people are killed every year in electrical accidents	

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PRESENTATION	APPLICATION
E. More surprisingly, the NIOSH report also reveals the number of firefighters who are also killed and injured annually in electrical incidents F. Electric Shock and Burn Hazards G. You often hear, in reference to electrical safety, that "it's not the volts that kill you but the amps." While this is partially true-- why do you see so many warning signs that read: Warning: High Voltage? H. Electricity can cause a variety of effects, ranging from a slight tingling sensation, to involuntary muscle reaction, burns, and death	Slide 8 – Electrical Hazards
I. The physiological effects produced by electricity flowing through the body include: 1. Perception - 1 mA a) At the lowest levels of current in the body, we experience perception where currents as low as a few millionths of an ampere can be perceived as a tingling sensation by most people	

PRESENTATION	APPLICATION
b) Perceptible currents are harmful under certain circumstances 2. Startle Reaction – 5 mA a) Startle reaction, a slight shock; not painful but disturbing, results in involuntary muscular reaction b) An average person can let go c) The reaction to current may cause injury from uncontrolled body movement (like falling from a roof or a ladder) d) Underwriter Laboratory (UL) uses 5 milliamperes for a 60-Hz current as the let-go limit 3. Muscle Tetanization – 6 to 30 mA a) Muscle tetanization, a result of a painful shock, is defined as the continuous tonic spasm of a muscle, the steady contraction of a muscle without distinct twitching	

PRESENTATION	APPLICATION

b) Tetanization results in several effects of concern including:

- ♦ The inability to let go of a gripped conductive part while the current flows from the part into the hand, the inability to move the body while the current flows from the conductive part into the body
- ♦ possible respiratory arrest if the current flows through the torso and interferes with breathing

c) Tetanization effects last only as long as the current flows

d) With the exception of respiratory arrest, when the current stops the effects stops as well

4. Respiratory Arrest – 50 to 150 mA

a) Extreme pain, respiratory arrest and severe muscular contractions occur between .5 to 1.5 amps

PRESENTATION	APPLICATION
5. Ventricular Fibrillation – 1 to 4.3 amps a) At 1 to 4.3 amps, ventricular fibrillation; the rapid, uncoordinated contraction of some portion of the heart muscle which causes irregular heartbeats and ineffectual pumping of the blood, is likely to occur b) Ventricular fibrillation victims usually die after a few minutes from the lack of blood circulation c) Unlike tetanization effects, ventricular fibrillation can be triggered by electric current passing through the heart d) Once started ventricular fibrillation is not spontaneously reversible in humans e) Nerve damage and death is most likely 6. Cardiac Arrest – 10,000 mA a) Lethal currents of 10 amps will cause cardiac arrest, severe burns and probable death	

PRESENTATION	APPLICATION
b) Look at the circuit breakers on your own home and see that most of the breakers are rated at 15 to 20 amps c) Each one of these circuits has enough voltage and amperage to seriously injury and potentially kill you	
	Slide 9 – Electrical Hazards
J. Resistance to Electricity 1. When you become part of an electrical circuit there are a number of variables that play an important role in human resistance to electricity, these include: a) Amount of current flowing through the body b) Pathway of the current through the body (hand-to-hand or hand-to-foot) c) Length of time the body is in the current d) Other factors that may affect the severity of the shock are: ♦ Body size and shape (muscle mass and body, the larger the person the more resistive)	

PRESENTATION	APPLICATION
♦ Area of contact (with conductive parts) ♦ Pressure of contact (of skin to the contacts) ♦ Moisture of contacts (sweaty skin will be more conductive than dry skin) ♦ Clothing (is yours conductive or insulated; jewelry is very conductive) ♦ Type of skin (callused hands opposed to back of hand)	Slide 10 – Electrical Hazards
K. Electrical shock is but one consideration when working around electrical circuits--burns are another L. Burns that can occur in electrical accidents include electrical, arc and thermal M. With electrical burns, tissue damage occurs because the body is unable to dissipate the heat from the current flow N. These types of burns are typically slow to heal	

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PRESENTATION	APPLICATION
O. Temperatures generated by an electric arc can melt nearby material, vaporize metal in close vicinity, burn flesh and ignite clothing at distances of up to 10 feet P. Arc-flash results from high currents arcing through the air and vaporizing material like copper and aluminum Q. These high currents are initiated by contact between two energized points R. Arc temperatures can reach 15,000 to 35,000 degrees S. Comparatively, the temperature on the surface of the Sun is around 10,800 degrees T. A firefighter should never pull the electrical meter as a means of shutting-down power to a building U. The potential for electrical arcing, described above, creates a risk that ranges from serious injury to death V. Instead firefighters should lock out the main disconnect next to the meter and lock out/tag-out the meter box to insure that someone does not inadvertently re-energize the system	

PRESENTATION	APPLICATION
IV. Roof Hazards A. Roof ventilation just got a little trickier when you have a PV array covering a portion of the roof B. Typically the firefighter would find a point on the roof just above the fire to effect ventilation C. Now you must consider several things: the weight of the PV array on a weakening roof structure and the fact that you may not be able to access the roof over the fire D. In this case, the point of ventilation should be at the highest point of the roof and as close to the fire as possible E. Roof vents pose a significant trip hazard to fire fighters conducting roof ventilation operations F. You know to avoid trip hazards posed by vent stacks, skylights and other obstacles on the roof G. you need to also consider walking and working around the PV array and in as many cases solar water heating and swimming pool heating collectors	Slide 11 – Roof Hazards

PRESENTATION	APPLICATION
H. A PV system installed during new construction or retro-fitted onto an existing building adds weight to the roof assembly 1. Light-weight constructed buildings are engineered for every consideration except for the event of a fire 2. In light-weight construction, trusses are widely used to span wide areas without the need for vertical supports, reducing both material and construction costs 3. Under ordinary conditions, trusses work well 4. However, trusses often fail suddenly and totally during fires 5. Both wood and metal trusses are made of interdependent members which all fail if one member fails 6. Adjacent trusses, in their weakened state, are then unable to carry the additional load and these also fail in quick succession 7. The metal gusset plates that hold wood truss components together may fail quickly as fire consumes the wood in which the gusset teeth are shallowly embedded	

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PRESENTATION	APPLICATION
8. It is impossible for crews operating at a fire to predict the time or extent of a collapse since they cannot see how many trusses are affected, which components, and to what extent 9. Under fire conditions, because of the extra weight of PV systems, even on roofs engineered for the extra weight, the roof could be prone to faster collapse 10. This is a distinct danger and area of caution for firefighters on the roof and firefighters and occupants under the roof 11. Many firefighters have been killed in collapses attributed to trusses, particularly wooden ones, since the 1970s 12. Incident commanders and/or safety officers typically consider the presence of trusses in their fireground risk analysis I. Important Note: The question you ultimately have to ask yourself: Does it really matter when you are lying on the ground seriously injured or dead whether or not it was the shock or the fall that put you there?	

PRESENTATION	APPLICATION
	Slide 12 – Battery Hazards
V. Battery Emergencies	
A. As a rule, batteries do not burn; or rather, they burn with great difficulty	
B. If batteries are exposed to fire, however, the fumes and gases generated are extremely corrosive	
C. Spilled electrolyte can react and produce toxic fumes and release flammable and explosive gases when it comes into contact with other metals	
D. Due to the potential of explosive gases, prevent all open flames and avoid creating sparks	
	Slide 13 – Battery Hazards
E. In emergency involving batteries, always wear full protective clothing and self-contained breathing apparatus (SCBA) on positive pressure	
F. Extinguish lead-acid battery fires with CO2, foam or dry chemical fire extinguishers	
G. Do not use water	
H. Never cut into the batteries under any circumstances!	

PRESENTATION	APPLICATION
I. Even though the voltage generating system may be disconnected from the battery bank, the batteries themselves still have potential for electrical shock J. If the battery is punctured by a conductive object, assume that the object has electrical potential	
	Slide 14 – PPE
VI. Personal Protective Equipment and Tools A. Firefighters who are exposed to the hazards of structural firefighting should be provided with and use the protective ensemble that meets the applicable requirements of: 1. NFPA 1971, "Standard on Protective Ensemble for Structural Firefighting (2000) and 2. NFPA 1500, Chapter 7 Personal Protective Equipment (2002). 3. This would include turnout pants, coat, boots, gloves, hood and helmet 4. Respiratory protection should also meet the NFPA 1500	

PRESENTATION	APPLICATION
5. This level of protection will provide the level of safety to all the hazards, electrical and chemical, described in this text	
B. Jewelry such as watches, rings, and necklaces are all a good conductor of electricity and as such should not be worn around electrical components	
	Slide 15 – PPE
C. When working in close proximity to electrical circuits, use insulated hand tools	
D. To check for electricity flowing between two contacts an AC/DC meter should be employed	
E. Typically, hot sticks on many engines can only detect alternating current	
F. When operating any electrical testing equipment follow the manufacturers recommended use, maintenance, and testing of the equipment	
	Slide 16 – ER to PV
VII. Emergency Response Involving Photovoltaic Systems	
A. Several things need to occur during the size-up of a structural emergency that takes into consideration PV technology	

PRESENTATION	APPLICATION
B. Arriving firefighters need to scan the roof to see if there are any solar related modules	
C. The firefighter tasked with locking out and tagging out the electrical system at the electrical service meter should relay information back to the incident commander of any warning labels or extra junction boxes marked for the PV system	
D. The incident commander should relay the information on to the rest of the emergency response team	
E. Where there are accessible system disconnects at the inverter, battery controller, and battery bank these too should be locked out and tagged out as an extra measure of electrical safety	
	Slide 17 – ER to PV
F. Realize that in day time firefighting operations the solar panels are still generating electricity	
G. Care should be taken not to cut into or walk across the PV modules or array	
H. Breaking through the protective glass could potentially release all of the energy inherent in the entire PV system	

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PRESENTATION	APPLICATION
I. If a flat roof is completely covered with a PV array, consider cross ventilation of the building	Slide 18 – ER to PV
J. You cannot effectively block all the sunlight with foam or salvage covers during a day time operation	
K. During night time operations you do not have to worry about the PV system generating electricity	
L. Use of spotlights during an evening operation is not bright enough to generate electricity from the PV system	
M. However, the brightness of a lightening storm could send a surge of power though the system	
N. Lightening is the only other light source that approximates the sun's intensity at 1,000 watts per meter squared	
O. If conduits and wires are cut into during an evening firefighting operation, they could become energized by the PV panels in the daytime exposing personnel to potential shock or reigniting a fire via an electrical short	

PRESENTATION	APPLICATION
P. Care should be taken not to cut into wiring, conduits, or raceways	
	Slide 19 – ER to PV
VIII. What To Do in a PV Emergency	
A. Always wear protective clothing and SCBA	
B. Avoid wearing jewelry	
C. Use hand tools with insulated handles	
D. Locate battery storage area (if applicable)	
E. Be aware that biting and stinging insects could inhabit the module frame and junction boxes	
F. Lock out/Tag out main electrical panel	
1. This single act will isolate the PV system from the rest of the building wiring system	
G. Lock out/tag out system disconnects at the module, controller, batteries, and/or the inverter	
1. This will provide an extra margin of safety	

PRESENTATION	APPLICATION
H. Ventilate the roof at the highest point of the roof over the fire without cutting through the PV array I. Extinguish lead-acid battery fires with CO2, foam or dry chemical fire extinguishers J. Should a short in the wiring system start a fire in the PV array use Class C extinguishing agents- CO2 or dry chemical K. Should the array become engulfed in a roof fire, use water in a fog pattern on the PV array **IX. What Not To Do in PV Emergency!** A. To ensure that you are not a victim of electrical shock from a PV system there are several things that you should not do: 1. Do not step on, break or smash a PV module 2. Do not try to ventilate a roof through a PV array 3. Do not contact electrolyte from lead acid batteries 4. Do not cut conduit or wiring a) Cutting PV wiring during a night time operation is not recommended	

PRESENTATION	APPLICATION
b) Sunlight the next day could activate the PV array causing loose wiring to short out and rekindle a structural fire or seriously injury someone 5. Do not cut into system components like the charge controller, batteries or inverter 6. Do not pull the electric meter from the main electrical panel under any circumstance! B. As a rule, fire fighters should treat the photovoltaic system the same way you would treat electric battery systems C. Always wear protective clothing and self contained breathing apparatus D. Care should be taken when operating around PV systems; you should not cut in to the panels or wiring system and you should lock out/tag out associated disconnects	Slide 20 – Summary

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PRESENTATION	APPLICATION
X. Summary A. Photovoltaic technology is around you every day and it is here to stay! B. Your fundamental understanding of photovoltaic systems will improve your confidence in working with and around solar technology safely C. The photovoltaic industry are counting on the fire service industry to operate safely and effectively around photovoltaic systems	