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Accelerated Aging Test for Plastic Scintillator Gamma Ray Detectors

Richard Kouzes

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Pacific Northwest National Laboratory
Richland, Washington 99352

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Executive Summary

Polyvinyl toluene (PVT) and polystyrene (PS), collectively referred to as “plastic scintillator,” are synthetic polymer materials used to detect gamma radiation, and are commonly used in instrumentation. Recent studies have revealed that plastic scintillator undergoes an environmentally related material degradation that adversely affects performance under certain conditions and histories. A significant decrease in gamma ray sensitivity has been seen in some detectors in systems as they age.

The degradation of sensitivity of plastic scintillator over time is due to a variety of factors, and the term “aging” is used to encompass all factors. Some plastic scintillator samples show no aging effects (no significant change in sensitivity over more than 10 years), while others show severe aging (significant change in sensitivity in less than 5 years). Aging effects arise from weather (variations in heat and humidity), chemical exposure, mechanical stress, light exposure, and loss of volatile components. The damage produced by these various causes can be cumulative, causing observable damage to increase over time. Damage may be reversible up to some point, but becomes permanent under some conditions.

It has been demonstrated that exposure of plastic scintillator in an environmental chamber to 30 days of high temperature and humidity (90% relative humidity and 55°C) followed by a single cycle to cold temperature (-30°C) will produce severe fogging in all PVT samples. This thermal cycle will be referred to as the “Accelerated Aging Test.” This document describes the procedure for performing this Accelerated Aging Test.

Acronyms and Abbreviations

AAT	Accelerated Aging Test
NIST	National Institute of Standards and Technology
PMT	photomultiplier tube
PNNL	Pacific Northwest National Laboratory
PS	polystyrene
PVT	polyvinyl toluene
RH	relative humidity

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1 Introduction

Polyvinyl toluene (PVT)-based and polystyrene (PS)-based (referred to as “plastic scintillator” in this report) gamma-ray detectors are used widely in many applications. A significant decrease in performance has been observed in some plastic scintillator based gamma-ray detectors in systems as they age. The degradation of sensitivity of plastic scintillator over time is due to a variety of factors, and the term “aging” is used to encompass all factors. Some plastic scintillator samples show no aging effects (no significant change in sensitivity over more than 10 years) while others show severe aging (significant change in sensitivity in less than 5 years). Aging effects arise from weather (variations in heat and humidity), chemical exposure, mechanical stress, light exposure, and loss of volatile components. The damage produced by these various causes can be cumulative, causing observable damage to increase over time.

The degradation of plastic scintillator in cold environments has been observed to be associated with internal “fogging” of the plastic. The photos in Figure 1.1 show a laboratory induced example of a fogging phenomenon in a slab of PVT plastic, which fills the interior, compared to a clear piece of PVT. Studies of this fogging phenomenon by Pacific Northwest National Laboratory (PNNL) are presented in the literature [Cameron 2014]. The conclusion reached in these research studies was that water plays the key role in causing the observed fogging in plastic scintillator. There may also be other phenomena at work in addition to this one in inducing the observed fogging. This fogging has been observed to occur under the specific circumstances where there is an extended series of periods of high temperature and humidity followed by extreme cold temperatures.

Figure 1.1. Internal fogging of PVT (left) after accelerated aging compared to unexposed PVT (right).

When used for gamma ray detection, the plastic scintillator slabs have one or more photomultiplier tubes (PMTs) mounted on one end and are wrapped with aluminum foil as a reflector. This in turn is wrapped with tape and vinyl wrapping to make the plastic scintillator panel light tight. This wrapping does not generally produce a seal adequate to exclude water vapor. The observed scintillation signal from the plastic scintillator by the PMTs is recorded as a gross count value above a low-energy threshold, below a high-energy threshold, and may be further subdivided into regions-of-interest.

It has been demonstrated that exposure of plastic scintillator in an environmental chamber to 30 days of high temperature and humidity [90% relative humidity (RH) and 55°C] followed by a single cold cycle to -30°C will produce severe fogging in all PVT samples [Cameron et al. 2014]. This thermal cycle will be referred to as the “Accelerated Aging Test.” The following Sections describe the procedure for performing this Accelerated Aging Test (AAT) for un-instrumented samples of plastic scintillator and for instrumented panels.

2 Accelerated Aging Test of Material

The Accelerated Aging Test can be applied to plastic scintillator material samples or fully instrumented panels of plastic scintillator. This section discusses the AAT for material samples.

The Test Samples are recommended to be at least 20 cm x 20 cm x 5 cm. In addition to the Test Sample(s) that will go through the rigors of the test campaign, two Control Samples are also required. The first is the Ambient Control Sample, prepared in the same manner as the Test Sample(s), which will be kept at ambient room conditions during the entire test. The second is the Bare Control Sample, which is a plastic scintillator sample with no covering placed in the environmental chamber with the Test Samples.

Testing takes place in an environmental chamber able to control temperature and humidity. The test is designed to evaluate whether a gamma-ray detector based on the material will perform correctly under the environmental extremes described in ANSI N42.35 [ANSI 2015], i.e., ability to operate from -30°C to +55°C.

In order to complete the test, the plastic scintillator must be examined at the end of the test campaign, requiring the removal of any covering of the plastic to observe the level of fogging that is present. Passing the Test would be demonstrated by the lack of fogging in the Test Samples. A measure of fogging at the end of the test is recorded using a zero to ten scale related to the severity of the observed damaged, with zero indicating no fogging.

The Accelerated Aging Test is executed through the following steps.

Step 1: *Material placed in environmental chamber at ambient temperature* – The Test Sample(s) are placed in the environmental chamber along with the Bare Control Sample.

Step 2: *Extended exposure to high temperature and humidity* – The Test Sample(s) temperature is raised rapidly (in ~30 minutes) in the environmental chamber to 55°C[1], with 90% relative humidity, for 30 days. At the end of the test period, the Test Sample(s) are brought rapidly to ambient temperature (in ~30 minutes). Any standing water is removed.

Step 3: *Low temperature exposure* – The temperature of the environmental chamber is rapidly reduced (in ~30 minutes) to -30°C for at least 4 hours, and up to 24 hours. The Test Sample(s) are then brought rapidly to ambient temperature (in ~30 minutes).

Step 4: *Final material examination* – After returning to ambient temperature, the Test Sample(s) are removed from the environmental chamber and photographed. Any covering of the Test and Control Samples is removed in order to evaluate the condition of the plastic. An evaluation of the clarity[2] of the samples is made (on a 0-10 scale, where 0 is clear) and recorded initially and daily over a one-week period. The means for this ranking is a light transmission measurement. Document the sample with photographs.

Step 5: *Documentation* – A report of the testing results is prepared.

[1] When testing samples, a higher temperature of 65°C may be used to accelerate the water permeation process by about a factor of 1.6 over the 55°C rate [Keller 2016]. This temperature is still well below the ~80°C softening point for PVT.

[2] Clarity may be determined by eye or with an instrument that measures light transmission and scattering in a repeatable manner.

3 Accelerated Aging Test of Instrumented Panel

The Accelerated Aging Test can be applied to plastic scintillator material samples or fully instrumented panels of plastic scintillator. This section discusses the AAT for fully instrumented panels of plastic scintillator.

An instrumented plastic scintillator gamma-ray detector consists of the plastic scintillator, photomultiplier tubes (PMTs) with bases mounted on one end, a reflective covering, any encapsulation material, and a wrapping of material to prevent light intrusion. For this test, a signal must be recorded from the PMTs. The PMTs are typically mounted on a metal plate that is screwed onto the end of the plastic scintillator panel. National Institute of Standards and Technology (NIST) traceable sources are used during the test campaign, typically a ^{60}Co source.

Testing takes place in an environmental chamber able to control temperature and humidity over the required range. The test is designed to evaluate whether a gamma ray detector based on the material will perform correctly under the environmental extremes described in ANSI N42.35 [ANSI 2015], i.e., ability to operate from -30°C to +55°C.

At the end of the test, any wrapping of the plastic scintillator is removed to examine the state of clarity of the material. A measure of fogging severity on a zero to ten scale is used, with zero indicating no fogging.

The Accelerated Aging Test is executed through the following steps.

Step 1: *Detector sensitivity baseline test* – The detector is made operational as it would be used in the field. A source is used at the standard 2 m distance at ambient temperature to establish the nominal sensitivity of the detector, including center and heel-toe measurements and resulting spectra.

Step 2: *Detector sensitivity in environmental chamber at ambient temperature* – The detector is placed in the environmental chamber and made operational. The detection sensitivity is measured in a standard configuration while in the chamber, typically through the wall of the environmental chamber so that the source is not subjected to the environmental changes. The sensitivity is compared to the sensitivity previously measured outside the chamber.

Step 3: *Detector sensitivity at high temperature* – The detector temperature is raised (in ~30 minutes) in the environmental chamber to 55°C at ambient relative humidity for 4 hours, followed by a test of its detection sensitivity in the standard configuration while in the chamber, as in the last step. The sensitivity is compared to the sensitivity at ambient temperature. The detector is returned to ambient temperature (in ~30 minutes).

Step 4: *Detector sensitivity at low temperature* – After returning to ambient temperature, the detection sensitivity of the detector in the standard configuration while in the chamber is measured. The temperature of the environmental chamber is then reduced (in ~30 minutes) to -30°C for 4 hours, followed by a test of its detection sensitivity in the standard configuration while in the chamber. The sensitivity is compared to the sensitivity at ambient temperature. The detector is returned to ambient temperature (in ~30 minutes).

Step 5: *Detector sensitivity at ambient temperature* – After returning to ambient temperature for 4 hours, the detector sensitivity is measured in the standard configuration while in the chamber prior to the extended exposure to high temperature for accelerated aging. The sensitivity is compared to the sensitivity previously measured at ambient temperature.

Step 6: *Extended exposure to high temperature and humidity* – The detector temperature is raised in the environmental chamber (in ~30 minutes) to 55°C, with 90% relative humidity, for 30 days. The detector sensitivity with a source is measured in the standard configuration initially and at least weekly while in the chamber. The sensitivity is compared to the sensitivity previously measured at ambient temperature. At the end of the test period, the detection sensitivity is measured while in the chamber. The detector is returned rapidly to ambient temperature (in ~30 minutes). The detection sensitivity is measured while in the chamber.

Step 7: *Detector sensitivity at low temperature* – The temperature of the environmental chamber is rapidly reduced (in ~30 minutes) to -30°C for 4 hours to 24 hours, followed by a test of its detection sensitivity in the standard configuration while in the chamber. The sensitivity is compared to the sensitivity at ambient temperature. The detector is rapidly returned to ambient temperature (in ~30 minutes).

Step 8: *Final Detector performance* – After returning to ambient temperature for 4 hours, the detector sensitivity is measured in the standard configuration while in the chamber. The sensitivity is compared to the previous sensitivity at ambient temperature. The detector is then removed from the environmental chamber, and source testing is performed at a standard 2 m distance at ambient temperature, including heel-toe and center measurements and resulting spectra.

Step 9: *Additional Temperature Cycle Test* – The detector may be run through an additional series of temperature swings from 55°C to -30°C for a period of time to determine if additional temperature cycling will have any deleterious efforts on the gamma ray detector. A typical series would be 4 hours hot and 4 hours cold repeated three times per day for one week.

Step 10: *Documentation* – A report of the testing results is prepared.

4 Conclusions

Accelerated Aging Tests have been defined that can be used for potentially inducing damage into plastic scintillator. These tests can be used to validate mitigation methods such as heaters or encapsulation of the plastic scintillator. The Tests can be used on complete plastic scintillator panels to indicate whether efforts to prevent damage of the plastic scintillator have succeeded.

This Accelerated Aging Test approach has been included as an informative Appendix in the ANSI N42.25-2015 standard [ANSI 2015].

5 References

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