TECHNICAL MEMORANDUM

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REVISION HISTORY: FEB. 12, 2009 Clarification on page 4.

AUG. 3, 2007 Title changed. Scope of the document was changed to address post irradiation heat treatment of B3 film dosimeters and post irradiation heat treatment effectiveness testing. This is considered a major revision that replaces the prior document.

POST IRRADIATION HEAT TREATMENT OF B3 DOSIMETER PRODUCTS

RELEASE DATE: FEBRUARY 12, 2009

B3 film dosimeters can exhibit a post irradiation color development change over time that is dependent on the temperatures and doses the B3 dosimeters were exposed to during the irradiation process. The post irradiation color changes will continue for a number of hours unless an effective heat treatment process is applied to complete the color development which stabilizes B3 dosimeter response.

This Technical Memorandum and other GEX documents recommend heat treatment of B3 film dosimeters after they have been irradiated to complete B3 dosimeter color development and eliminate post irradiation measurement variability. Other GEX customer information documents also contain information on B3 dosimeter performance characteristics (e.g. GEX Technical Memorandum 100-205 B3 Film Dosimetry).

SIGNIFICANCE OF POST IRRADIATION DOSIMETER RESPONSE VARIANCE

One of the most significant factors in determining the accuracy of a dosimetry system is the post irradiation stability of the response of the dosimeter being used. The impact of post irradiation dosimeter response variance can account for a significant portion of the overall uncertainty of the dosimetry system. The amount of post irradiation change is typically non-linear in that a higher percent change generally occurs in the lower doses with little or none associated with higher doses. In the end, the post irradiation response component will generally contribute more to the overall uncertainty than any other single component.

The response signal of some dosimeters may be highly stable over a long time period but suffer a high degree of initial short term response signal instability. These dosimeters can be managed by simply controlling the initial holding time period needed before allowing measurements to be taken in order to provide sufficient time for the response signal to stabilize.

Other more difficult to manage dosimeters may exhibit unstable response immediately after irradiation and never achieve an acceptable level of stability but in fact only demonstrate both signal growth and fading. These dosimeters will add significantly to the overall dosimetry system uncertainty and at best may only be time control measured. These dosimeters cannot be managed with a simple time holding period before readout. They require use of multiple post irradiation time period calibration curves to best manage their post irradiation instability.

In the case of the B3 dosimeter, a simple effective post irradiation heat treatment process step is recommended that completely eliminates post irradiation variance in the dosimeters and renders them stable.

The following information is useful in understanding the requirements needed to establish an effective post irradiation heat treatment process

POST IRRADIATION COLOR CHANGE OF B3 FILM

Ionizing radiation events activate the B3 dye centers which in turn cause the B3 film to undergo a predictable color change from clear to deepening shades of pink magenta. The amount of color change is influenced by temperature during irradiation. The final color change in B3 dosimeters can take a number of hours to complete dependent on the dose of ionizing radiation and the temperatures experienced during the irradiation process. However, it is well understood that post irradiation heat treatment can complete the color development process in minutes and result in B3 dosimeters that will remain stable for a year or more.

POST IRRADIATION STABILITY OF B3 FILM DOSIMETERS

An effective post irradiation heat treatment process used on B3 radiochromic film dosimeters will render the dosimeters nearly 100% stable with less than a 1.0% detectable change in response per year. No other dosimeter that can be used in routine dosimetry can match the post irradiation stability of properly heat treated B3 dosimeters. Irradiated B3 film is available as certified references from Risø National Laboratory for use with their RisøScan dosimetry software system. Therefore, post irradiation heat treatment for B3 film dosimeters is strongly recommended. In addition, because the B3 film dosimeters are stable after a heat treatment process, they can also be used as references for the dosimetry system (see GEX Technical Memo 100-210, Genesys 20 – General Practices and Information, for detail on using B3 dosimeters as references).

HISTORICAL SPECIFICATION OF B3 FILM DOSIMETER HEAT TREATMENT

It was determined early on in the development of the B3 film dosimeter that heat treatment provided completion of the color development of the film. It was established by Arne Miller, the developer of B3, that post irradiation heat treatment in a box style incubator for a five minute time cycle at 60°C provided 100% color development and B3 dosimeters that were heat treated to these specifications would remain stable for more than one year. This specification has been used successfully at Risø since the early 1980s.

EFFECTIVE POST IRRADIATION HEAT TREATMENT PROCESS SPECIFICATION

A number of questions arise however when such a heat treatment specification gets expanded beyond a single user. For example:

- How much variation is acceptable in terms of the temperature?
- Are there maximum and minimum temperature range limits?
- Is there a minimum time limit or a maximum time limit at these temperatures?
- Does it matter how long after irradiation the heat treatment process is started?

GEX began its effort to develop a general specification for post irradiation heat treatment of B3 film dosimeters as a part of the release of its *WINdose Dosimetry System* in 1999. GEX utilized the Risø practice as a baseline for testing to determine answers to these basic questions. GEX verified the 60°C temperature by testing at temperatures ranging from 50°C to 70°C in 5.0°C

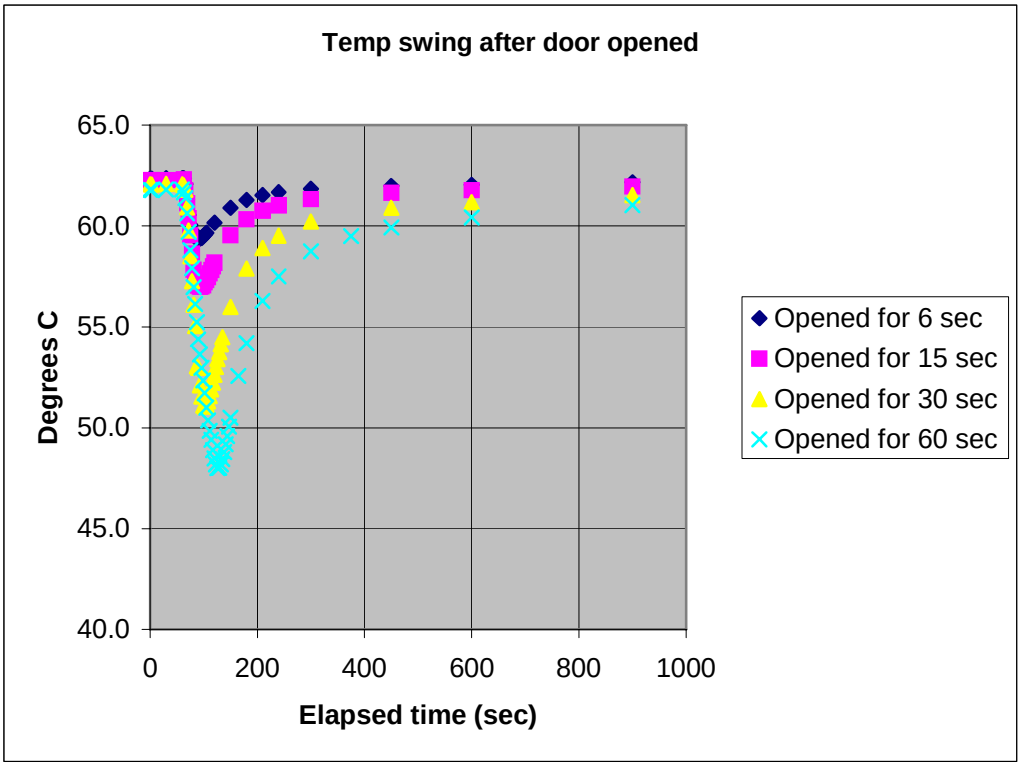
increments for times from 5 - 60 minutes in 5 minute increments. Beyond 60 minutes the intervals were changed to one hour up to 6 hours with a final time of 20 hours.

It was observed that temperatures below 55°C do not complete the color development and temperatures above 65°C could cause the B3 film surfaces to stick and even fuse together if they came into contact with one another.

The conclusions based on these tests led to establishment of the initial GEX user recommendations for use in establishing an effective B3 dosimeter post irradiation heat treatment process with typical box style irradiators. The recommendations indicated that temperatures between 55°C and 65°C could be used to satisfactorily heat treat both bare B3 film as well as pre-packaged B3 WINdose dosimeters using a minimum five minute time period for bare B3 film and a 15 minute minimum time for pre-packaged B3 dosimeters. The longer time recommended for the pre-packaged dosimeters was to accommodate the heat sink associated with the addition of the packaging material.

The initial testing in 1999 also confirmed that heat treatment at 60°C for times above 6 hours (results were for a single time period of approximately 20 hours) resulted in evidence of significant fading in the B3 film dosimeters. It was determined that a conservative maximum three hour time recommendation be established.

Studies of box style incubators were performed that demonstrated heat loss inside the incubator occurred when the door was opened to load and retrieve the B3 dosimeters and that it could take up to 10 minutes for the incubator temperature to recover.



Above are results obtained with a box style incubator set to 60°C with actual temperatures measured inside the B3 WINdose dosimeter pouch of approximately 62°C. The plot shows temperature recovery times associated with opening and closing the incubator to simulate dosimeter loading in the incubator.

While most box style incubators have an air temperature performance specification on the order of ±0.5°C, B3 dosimeter users are encouraged to perform temperature maps of their particular incubator systems to verify temperature uniformity inside the incubator.

NOTE: Heat treatment testing up to 70°C has not shown any indication of permanent damage B3 film dosimeters in terms of physical properties unless two B3 film surfaces come into direct contact. Post irradiation heat treatment on B3 response function does not show a detectable change. It should be noted however, that the surface of B3 film begins to soften at temperatures near 60°C and this softening is sufficient that two B3 film surfaces can stick to one another. GEX also recommends avoiding radiation process temperatures above 60°C.

RECOMMENDED HEAT TREATMENT TEMPERATURE SPECIFICATION

The post irradiation heat treatment specification temperature range (55°C to 65°C) determined in 1999 is not changed and can be used for effective heat treatment of B3 film dosimeters.

However, GEX has also determined that use of a temperature setting of 58.5°C ±1.0°C provides optimum B3 heat treatment results and is also an appropriate recommendation based on reported user success with this temperature setting. The 58.5°C temperature has been used internally by GEX since 2004 and has been demonstrated to be sufficiently high enough to provide 100% color development and also completely stabilize B3 film dosimeters. It is also been demonstrated to be sufficiently low enough to minimize the potential of B3 film surfaces becoming stuck together due to over heating.

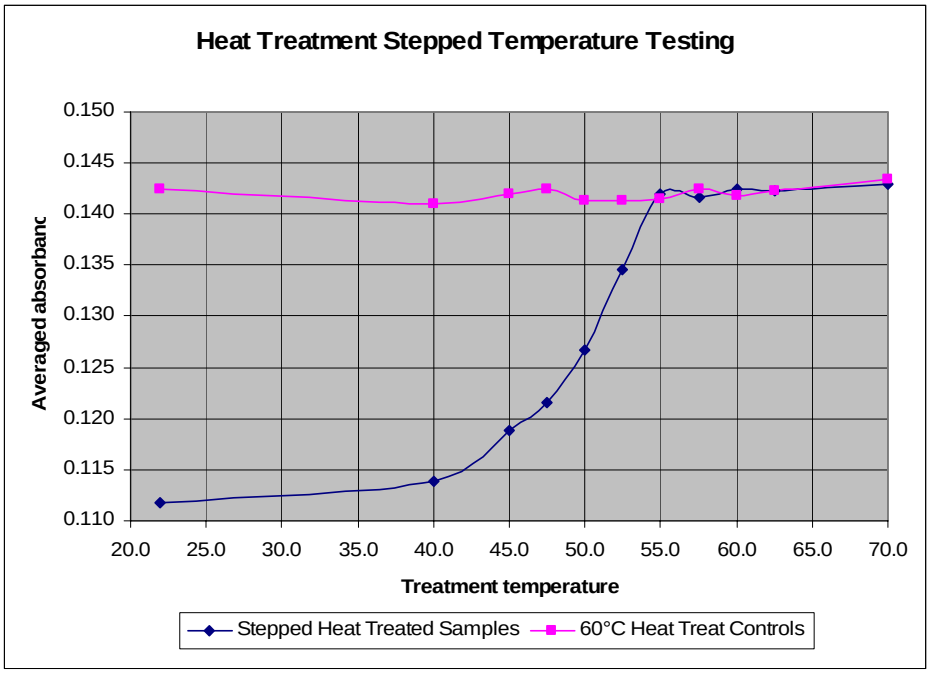
This refined 58.5°C optimum temperature setting was arrived at after working closely with several users that had reported B3 film surfaces sticking together following the heat treatment process. Investigations revealed significant temperature differences (>10°C) can exist between the upper and lower shelves in a box style irradiator. One simple resolution to improve temperature uniformity has been to restrict dosimeter placement to the middle or upper shelf of the incubator.

REQUIREMENTS FOR AN OPTIMUM HEAT TREATMENT SYSTEM FOR PACKAGED B3 FILM DOSIMETERS

Based on investigation of B3 user complaints about dosimeter films sticking together when there are more than 1 dosimeter in a sealed package, a series of tests were conducted that helped GEX to determine a more “optimum” heat treatment temperature of 58.5°C. The investigational testing coupled with B3 user requests for a more optimum post irradiation heat treatment system for B3 dosimeters caused GEX to develop performance requirements for a new heat treatment system that would optimize the post irradiation heat treatment process for B3 film dosimeters.

As part of development of the product specifications, the 55°C minimum temperature needed for 100% color development and B3 dosimeter stabilization was re-verified in 2004. More important however was the discovery that B3 film could actually reach full color development in less than 10 seconds at the 55°C temperature. It was observed during these investigations that a trigger-like color development in B3 film dosimeters occurs once the minimum temperature is achieved throughout the dosimeter.

GEX also confirmed the early Risø findings that B3 dosimeters that have undergone effective post irradiation heat treatment will remain stable (±1.0%) for one year or more. It was also confirmed that B3 dosimeter heat treatment intervention does not vary with the time after irradiation and that there is no measurable difference in the results observed with sets of dosimeters that were heat treated and measured immediately after irradiation compared with dosimeters that were held for up to 14 days before being heat treated and measured.



The above chart demonstrated confirmation of the 55°C minimum temperature requirement for post irradiation heat treatment of B3 film dosimeters.

THE OPTIMUM B3 HEAT TREATMENT SYSTEM

The output of the GEX performance requirements and subsequent product specification is the P4900 Micro Incubator. The P4900 was designed specifically for optimum post irradiation heat treatment of B3 dosimeters in either the WINdose of DoseStix format. The P4900 unit provides uniform heat treatment to ±0.2°C at the preset temperature (±1.0°C) displayed on the front of the unit.

GEX recommends a temperature setting of 58.5°C and has demonstrated that a heat treatment time in the P4900 unit of as little as two minutes can provide effective post irradiation heat treatment of GEX WINdose or DoseStix B3 film dosimeters.

GEX testing in the P4900 micro incubator confirmed that B3 dosimeters can be left at the 58.5°C temperatures for up to 3 hours without damage or measurable change in B3 dosimeter response values compared with the response values of B3 films that were held at the 58.5°C temperature for only a few minutes.

POST IRRADIATION HEAT TREATMENT OPTIONS

GEX continues to offer its P4800 Box Style Incubator System as a cost effective means for post irradiation heat treatment of B3 dosimeters although it promotes the P4900 Micro Incubator System as an optimum solution.

The P4901 Jenco Temperature Monitor and P4902 B3 Temperature Probe (DoseStix packaged B3 dosimeter pouch with a T Type thermistor) are accessories of the P4900 that provide a simple calibrated means of verifying the temperature settings of the P4900 as well as a means of demonstrating that temperatures within each of the cavities of the P4900 are uniform.

The following Appendix provides a test method to verify the effectiveness of the P4900 Micro Incubator System. This protocol can be easily modified for use in validating a P4800 Box Style Incubator system by simply changing the heat treatment times to accommodate the long dwell times needed with box style incubators to provide effective heat treatment using the same 58.5°C nominal temperature setting.

Guidance for validating the temperature and time needed to stabilize B3 dosimeters using the P4900 heat treatment system is found in the Appendix. Users that wish to re-verify the GEX testing and/or establish their own specifications are encouraged to contact GEX for assistance in planning their test protocol.

APPENDIX

RECOMMENDED PROCEDURE FOR VALIDATION OF P4900 HEAT TREATMENT SYSTEM.

B3 Post Irradiation Heat Treatment Effectiveness Testing in the P4900 Incubator
Post irradiation heat treatment of B3 dosimeters is intended to effectively complete the color development of B3 dosimeters resulting in post irradiation stable B3 dosimeters. The effectiveness of the post irradiation heat treatment process can be demonstrated by the stability of the B3 dosimeter absorbance over time. The time period should extend to or beyond the expected potential measurement and re-measurement time period in which B3 dosimeters may be used. GEX currently recommends use of 58.5°C (±1.0%) as the optimum post irradiation heat treatment temperature setting for the P4900.

Heat Treatment Effectiveness Verification Criteria
B3 dosimeter stability should be demonstrated by reproducible absorbance measurements of ±1.0% (excluding expected measurement instrument variance of 0.4%) compared with the initial B3 absorbance measurement throughout the complete time period tested in order to evidence B3 dosimeter stability.

Test Method (test method times may be changed for use with box style incubator testing)

1. Prepare a set of simultaneously irradiated B3 dosimeters (DoseStix or WINdose format). The dosimeters should be irradiated to a low dose level not greater than 10 kGy (or the lowest dose used at the facility if greater than 10 kGy). Use a minimum of 3 dosimeter packages per treatment time.
2. Test the 5 sub-groups of specified dwell times listed below:
    - 1 minute
    - 2 minutes
    - 4 minutes
    - 8 minutes
    - 16 minutes
3. Heat treat each sub-group at the 58.5 GEX recommended temperature setting using any of the micro incubator wells for the time specified.
4. Open the dosimeter pouches and measure and record the absorbances of all dosimeters in each of the sub-groups after applying heat treatment.
5. Re-measure each of the dosimeters once per day for a minimum of 7 days (Note: the stability time test can be extended to accommodate longer time periods)
6. Compare the average of subsequent absorbance values against the average of the first measurement value of the absorbance for each sub-group of dosimeters. Results should be within ±1% of the baseline absorbance values to satisfactorily verify stability.