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Quality Assurance and Quality Control in TLD Measurement

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ABSTRACT

TLD technique characterized by high precision and reproducibility of dose measurement is presented by addressing pre-readout annealing, group sorting, dose evaluation, blind tests, internal dose quality audit and external quality control audits. Two hundred and forty TLD chips were annealed for 1 hour at 400^0 C followed by 2 h at 100^0 C. After exposure of 1 mGy from ^{90}Sr irradiator TLds were subjected to pre-readout annealing at 100^0 C, then readout, sorted into groups each with nearly equal sensitivity. Upon repeating the procedures, TLDs having response >3.5% from group mean were dropped to assuring group stability. Effect of pre-readout annealing has been studied. Series of repeated measurements were conducted to stabilize calibration procedures and DCF generation using SSDL level ^{137}Cs calibrator, dosemaster, ionization chambers. Performed internal dose quality audits, blind tests and validated by external QC tests with King Abdulaziz City of Science and Technology.

Key words: *Group sorting, pre-readout annealing, blind test, external audit, quality assurance.*

INTRODUCTION

The quality of radiation measurements and hence the benefit derived from the radiation application depends strongly on the procedures and techniques used as well as the skills and training of personnel in the end-user institutions. Most of the large deficiencies in dosimetry measurement are believed to originate from the lack of suitable calibrations and overall Quality Control of the dosimetry system.

The International Atomic Energy Agency (IAEA) introduced mailed TLD system, the Regional Cooperative Agreement (IAEA/RCA) project, to strengthen and harmonize radiation protection infrastructure in Asian and Pacific Region aiming at exploring and upgrading the status of radiation protection and their technical abilities of measurements relevant to radiation protection in the member states [(1)].

With the introduction of new recommendation on Radiation Protection Principles by the ICRP 60 [(2)] and furthermore with the development of recommendations on the calibration methodology for radiation protection instruments for operational quantities by the International Organization for Standardization [(3)] , IAEA initiated second dosimeter intercomparison with a view to evaluating dosimetry systems abilities for conducting individual monitoring in terms of the ICRU operational

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quantities for photons, to provide access for the participants to photon field qualities for calibration of their systems.

A Quality Assurance (QA) and Quality Control (QC) program was applied to the TLD-based personnel monitoring department of the Greek Atomic Energy Commission following recommendations of ISO, IAEA and the European Commission(4). TLD technique characterized by high precision with an average readout standard deviation of 1.2% and reproducibility of dose measurement is presented by Yu et al.(5). Consistent procedures for the preparation, packaging, record keeping and readout, along with many QC checks are necessary to obtain reliable results in TL-dosimetry (6).

Characteristics of the TLDs that are particularly important for radiation dosimetry include variability of the TL response vs readout temperature and the variability of TL response related to annealing procedures. In view of a large number of radiation sources of different kinds being used in the kingdom for clinical and industrial applications as well as in research and teaching, it is planned to report in this paper a careful application of QA/QC techniques, addressing those factors, characterized by improved precision and reproducibility of radiation dose measurement using TLD-100 (LiF) chips.

MATERIALS AND METHODS

Irradiation

TLD-100 (LiF), widely used thermo-luminescent material, is considered to be the most suitable (7-8) for the present works. Two batches of 240 TLD-100 were annealed by using an automatic TLD oven model PTW-TLDO (Physikalisch-Technische Werkstatten, Freiburg, Germany). The pre-irradiation annealing procedure consisted of three steps; high and low temperature annealing according to the following duration: 1 hr at 400 ^{0}C immediately followed by 2 hrs at 100 ^{0}C, and finally 1 hr for cooling to room temperature.

The TLD chips were irradiated with ^{90}Sr and ^{137}Cs For each TL measurement background subtraction was performed. For each session of TLD exposure to radiation, up to 5 chips from the same group with about the same sensitivity as those used for measurement were set aside without any radiation. This baseline group then went through the same pre-readout procedure as the irradiated TLDs.

Identification of golden chips

The Golden chips were identified by careful analysis of the irradiated chips. TLD chips were readout within 24 hrs of irradiation and sorted into subgroups. In the first step, 90 chips were chosen from a batch of total number of 240 chips. After irradiation the readout session was carried out in uninterrupted manner. After readout, each TLD chip was kept in an assigned bin with identification number for sorting purpose.

This was done based on their statistical variation of recorded nC. Out of the 240 TLDs the chosen group of 90 represented the largest group in the statistical distribution having standard deviation below 10%, were identified as master chips. In the second step from these 90 master chips 10 Chips were identified with almost the same sensitivity, to within ± 3.5%, corresponding to standard deviation below 2.5%. These chips were identified as the Golden Chips to be used for the purpose of Dose Conversion Factor (DCF) generation.

Pre-read annealing (Preheating)

Cameron et al. [9] and Zimmerman et al.[10] proposed a standard pre-irradiation annealing procedure consisting of 400 ^{0}C (high temperature annealing) for 1 hour to de-excite all traps in the phosphor, followed by 80 ^{0}C for 24 hour (low temperature annealing) to redistribute traps to the desired single peak glow curve. An additional post-irradiation technique was suggested by Booth et al.[11]. In this procedure, TLDs were annealed for 1 hour at 400 ^{0}C before irradiation and then for 10-15 min at 100 ^{0}C after irradiation and before readout. We have followed here a simplified TLD annealing technique[5] characterized by high precision and reproducibility of radiation dose measurement. In this technique the TLDs are group annealed, sorted, and subjected to pre-readout annealing according to the procedure described as follows:

High temperature and low temperature annealing prior to irradiation and pre-readout annealing at low temperature after irradiation have been followed in the present work. High temperature annealing was accomplished as mentioned earlier using the PTW–TLDO microprocessor controlled furnace. The procedure of 400 ^{0}C for 1 hour, 100 ^{0}C for 2 hours and pre-readout heating at 100 ^{0}C were studied in a comprehensive way to determine the optimum pre-readout heating time and factors influencing this parameter. Response of TLDs were studied for 5 minutes, 10 minutes, 15 minutes, and 20 minutes pre-readout heating to determine which pre-heating duration yields the optimum result without affecting accuracy in dose assessment.

Generation of DCF

The numerical results obtained in the interpretation of individual monitoring of external radiation depend mainly on the accurate calibration of the radiation measurement instrument involved. This means the conversion of nC obtained by heating the TL chips to equivalent dose in mGy, which has been designated by Dose Conversion Factor (DCF). PTW UNIDOS Universal Dosemaster, coupled with PTW 10,000 cc spherical ion chamber type 32003 has been used for the reference dose measurements and thereafter, generation of DCF following as usual procedures. The measured dose/dose rate and DCFs are compared with that obtained using FARMER dosemaster (Saint-Gobain, UK).

Studies on TL response vs pre-readout annealing (preheat) time

It is well established that the standard Pre-irradiation annealing procedure at high temperature (400 ^{0}C for 1 hour) followed by low temperature annealing (100 ^{0}C for 2 hours) de-excites all traps in the phosphor. Two hours of the low temperature annealing resulted in the smallest standard deviation of 1.3%, the acceptance limit of the standard practice.

The effect of the duration of pre-read annealing at 100 ^{0}C for 1 hour was studied extensively with the following sources of radiation types: a) Standard reference source Sr-90 for beta radiation, and b) ^{137}Cs Calibrator for Gamma radiation. The TL chips from the same pre-sorted irradiated group were divided into five subgroups. The first subgroup was read directly following the irradiation and the remaining subgroups were then subjected to pre-read heating at 100 ^{0}C for 5 minutes, 10 minutes, 15 minutes, and 20 minutes respectively and then readout..

Intercomparison run with SSDL facility

After performing validation of TLD measurement by blind tests and internal audits, revalidation was done through participating intercomparison program with Secondary Standard Dosimetry Laboratory (SSDL) through the National Regulatory Authority, King Abdulaziz City of Science and Technology (KACST). Under the protocol followed by KACST, the TLD-100 chips are group annealed, sorted, and golden chips are identified by the standardized method.

Personal dose equivalent Hp(10) [deep dose] and Hp(0.07) [shallow dose] are determined. Fifteen TLD badges are mailed to KACST by postal mail for irradiation using SSDL facility at King Faisal Specialists' Hospital and Research Center, Riyadh. In addition, two control badges accompanied the package. Each TLD badge is irradiated individually in the SSDL facility to a unique dose.

The irradiated badges are then sent back to the participant by postal mail. Upon receiving the TLDs are readout as per the standard method stated in earlier section. The dose records are then sent to KACST for evaluation. The bias (defined to be the absolute value of mean of the relative deviation or relative error between the measured doses by the participant and the delivered dose for individual TLD badges), the standard deviation of these, and the total of bias and standard deviation are the testing parameters of the KACST QC checks.

RESULTS AND DISCUSSION

Group sorting and identification of golden and master chips

After irradiation all the 240 TLDs were assigned into five sorted group based on their 'sensitivity'; according to their collected charge in nC in various ranges. The chips having approximately the equal sensitivity were grouped together. The TLDs corresponding to 10% and 2.4% standard deviation were selected and removed from each group to constitute the 'Master chips' and ' Golden chips, respectively.

Preheat studies with ^{90}Sr standard source

A batch of 50 TLD chips are arranged in a 'merry-go-round' circular annealing tray irradiating them keeping a constant distance as it revolves around its center. The chips are irradiated with a constant dose from ^{90}Sr source.

The response data shows a wide-ranging sensitivity of the chips varying up to 20%. However a sub-group with Maximum Deviation (D_{max}) 8.39% was produced considering the values of response that seem to be close enough. The standard deviation was found to be 4.16 that yielded a Coefficient of Variation (CV) of 5.42%. The desired standard deviation is 1.5% corresponding to the sensitivity D_{max} within 3.5%.

This leads to the concept of pre-readout annealing i.e. preheating to obtain a better representative sub-group with improved CV and D_{max}, as defined above. The same number of chips were then annealed following the standard high and low temperature annealing procedure, and then irradiated keeping all other conditions same as before but the preheating for 5 minutes, 10 minutes, 15, minutes, and 20 minutes were applied, respectively.

Second batch of TLD-100 chips irradiated with the same dose at ^{90}Sr source and readout after 5 minutes preheat at 100^0C. The preheat technique improved uniformity of the response sensitivity. A better sub-group with more number of chips within the group could be formed with lower D_{max} with a value of 6.02%. The standard deviation obtained is 2.33 with the corresponding CV 3.36%. A significant improvement towards the goal can be noticed to occur due to 5 minutes preheat. The CV and D_{max} are still not within the acceptable range.

The 10 minutes preheat further improved uniformity of the response sensitivity. The D_{max} value, 3.7%, in this case came very close to the accepted value of 3.5%. The standard deviation obtained is 1.78 with the corresponding CV 2.20%. These values are in close agreement within the acceptable limit.

The 15 minutes preheat results are more or less same as that of 10 minutes results. The response sensitivity almost yielded the same scenario. The sub-group properties remain approximately the same. The D_{max} value within the sub-group increased a little, 4.5%, in this case. The standard deviation obtained is 1.88 with the corresponding CV 2.26%. These values are marked by some deviation from the previous set of results for 10 minutes preheat.

The 20 minutes preheat further worsen the results. The uniformity of the response sensitivity that was observed in the cases of 10 –15 minutes cases got unstable. The number of chips in the sub-group that could be formed with the limited magnitude of response sensitivity was less than the earlier group even with the D_{max} value of 9.7% with a corresponding CV of 4.20%. These values clearly demonstrate the disarray of the uniform response sensitivity with preheating time more than 15 minutes. Fig. 1 represents the effect of pre-readout heating to obtain the optimum value of the preheat time when using ^{90}Sr for irradiation.

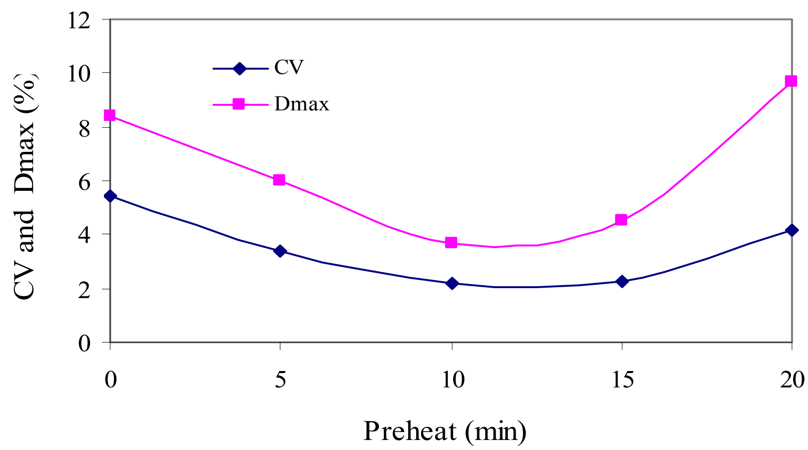

Fig.1. Post irradiation pre-readout annealing. Irradiated with ^{90}Sr Irradiator .

Preheat studies with gamma rays from ^{137}Cs standard calibrator

The same procedure as above was applied in the case of gamma rays from ^{137}Cs. Twenty pre-sorted TLD-100 chips in the first batch are readout directly after irradiation. The CV and D_{max} are found to be 7.47% and 10.54% respectively. Then twenty chips in the second batch are irradiated and readout in steps of 5 minutes, 10 minutes, 15 minutes, and 20 minutes preheat. CV for the above steps are 6.7%, 3.4%, 4%, and 8.2%, respectively.

The maximum deviation form the sub-group mean, D_{max}, are 5.9%, 3.3%, 3.7%, and 12.94%, respectively. It is clear from the analysis of these results that the minimum value of CV 3.4%, and D_{max} 3.3% is observed for 10 minutes preheating sub-group. It is almost uniform in the 10 to 15 minutes pre-readout heating range and starts to deteriorate as the preheating time is increased. Result demonstrates that preheating improves the precision of measurements significantly.

The obtained value of CV is not in the recommended range of 1.5%; while the D_{max} value 3.3% is within the recommended value of 3.5%. Although the value of CV considerably came down to 3.4% for 10 minute preheat readout compared to 7.4% without preheat treatment.

However, with the increased number of chips, sorting into subgroups or batches based on approximately equal sensitivity, identification of golden chips, careful irradiation under same conditions, and preheating (10 to 15 minutes) before readout may improve the quality of the measurements. Fig. 2 shows the effect of pre-readout heating to obtain the optimum values of the preheat time for gamma ray irradiation from ^{137}Cs Calibrator.

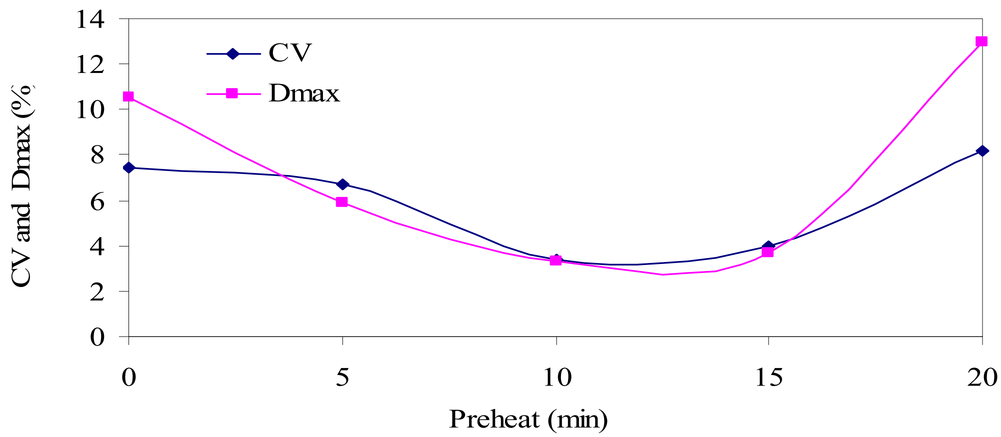

Fig.2. Post irradiation Prereadout annealing. Irradiated with Cs-137 Irradiator.

A careful analysis of the results of these two studies with corresponding figures showing the relationship between TL signal and the duration of the pre-readout annealing demonstrates that the optimum preheating time lies between 10-15 minutes, in agreement with the work of Yu et.al[(5)]. More specifically 10 minutes preheat is found to be the most appropriate preheat time. The sensitivities of the TLDs to radiation showed a gradual reduction as the pre-readout annealing time increased to 10–15 minutes range.

In all cases under study the TL response showed a minimum Coefficient of Variation (CV) at 10 minutes pre-readout heating. For shorter duration pre-readout annealing the CVs were found to be significantly greater while the D_{max} value decreased with pre-readout annealing in 10–15 minutes range; which means that the sensitivity of the TL signals were more homogeneous yielding uniformity in response. This suggests that 10-15 minutes pre-readout annealing removes some unstable low temperature peaks from the glow curve of TLD-100.

This helps to obtain consistent reading from the TLD-100 chips. The procedure of 400 ^{0}C for 1 h, 100 ^{0}C for 2hrs; and 100 ^{0}C pre-readout for 10 min may be treated as the ‘Standard Annealing Procedure’. It has been observed that the group sorting provides the precision of TLD measurement, while the pre-readout annealing improves the accuracy by removing the unstable low temperature peaks.

Calibration and DCF generation

The reference source ^{137}Cs was used in the air kerma unit, mGy, with test irradiation range of 0.3 to 10 mGy. The testing procedures and performance of the dosimetry system in radiation field similar to those encountered in practical routine monitoring were conducted. Series of experiments were conducted to measure air kerma doses by Farmer dosemaster with 600 cc ion chamber and PTW UNIDOS dosemaster coupled with 10000 cc PTW ion chamber.

The precision in the results of the several measurements at 1 m, 0.5 m, and 0.3 m are within 0.2%. The relative error between the calculated dose and measured dose with FARMER dosemaster is -8% at 0.5-m; the same for the UNIDOS measurement is -1.43%. A significant improvement in relative error between the calculated dose and the UNIDOS measurement can be distinguished. For DCF generation dose rates measured by the PTW UNIDOS dosemaster was used as reference doses. At one meter SSD the relative per cent of errors were found to be higher in both the cases.

Fig. 3 demonstrates the reproducibility of the DCF at 0.5 meter using the reference dose measured with Farmer dose master. The Coefficient of Variation in the measurement is 3.2 % for deep dose and that for shallow dose 6%. The generated DCF differs with the earlier measurements by -2.9%. The reproducibility of DCF was verified by internal comparison. The CV in the reproducibility measurements stabilized within 3.2%.

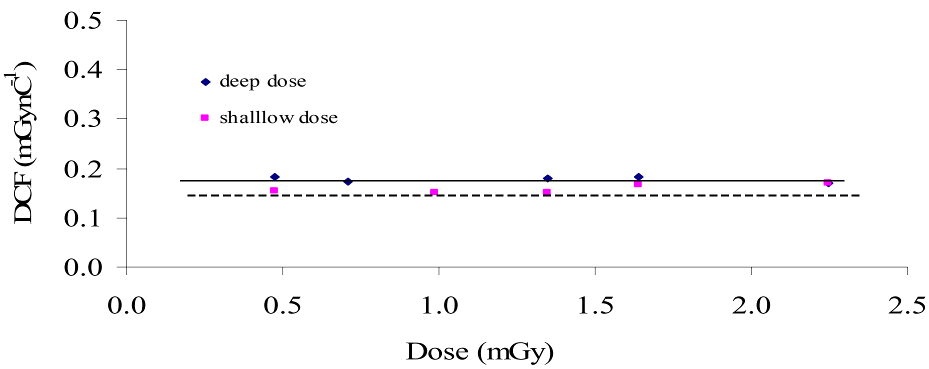

Fig. 3. Reproducibility of Dose Conversion Factor (DCF)

Fig. 4 represents the reproducibility of DCF for the specified two cases i.e. (AL-1 mm) for deep dose and ABS layer for shallow dose at 0.5 meter using PTW UNIDOS dosemaster coupled with PTW UNIDOS 10000 cc ion chamber. The average of DCF at 0.5 m for deep dose is 0.1824 ± 0.005 (CV: 2.7 %). The average of DCF at 0.5 m for shallow dose is 0.1606 ± 0.01 (CV: 6 %).

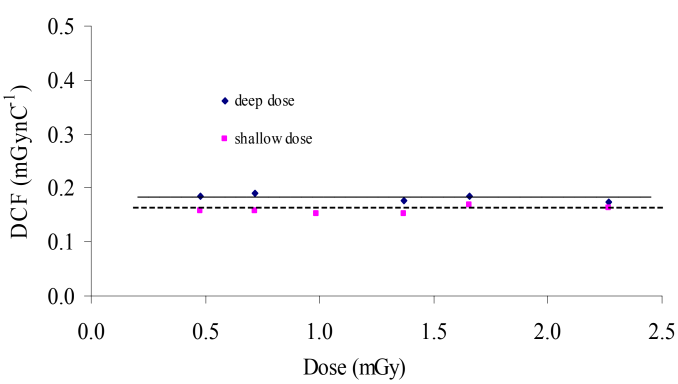

Fig. 4. Reproducibility of Dose Conversion Factor (DCF) .

It has been observed that using PTW UNIDOS dosemaster coupling with 10000 cc improved the generated DCF significantly. The percent of CV reduced to 2.7% compared to that (3.2%) measured with Farmer dosemaster.

Internal audit

In the process of validating by Internal Audit Process repeated measurements, analyses, calculations and recalculations were accomplished. The relative error between the known measurements and blind test is 3.6% for the estimation of deep dose and that for shallow dose 2.2%. The results of the blind tests contributed further to the reliability of the procedures followed for dose assessment.

Intercomparison program

Quality control tests were performed with the National regulatory Authority (KACST) for response reproducibility. The fluctuations of our measurements with those of the true values are shown in Table 1.

Table 1. Results of the intercomparison program with SSDL facility through the national regulatory authority, KACST.

Test parameters	Results of reading	Acceptable reading
First intercomparison		
Bias |B|	0.27	≤ 0.30
Standard deviation	0.06	≤ 0.35
Total	0.33	≤ 0.50
	Second intercomparison	
Bias |B|	0.23	≤ 0.30
Standard deviation	0.07	≤ 0.35
Total	0.30	≤ 0.50
	Third intercomparison	
Bias |B|	0.26	≤ 0.30
Standard deviation	0.08	≤ 0.35
Total	0.35	≤ 0.50
	Fourth intercomparison	
Bias |B|	0.13	≤ 0.30
Standard deviation	0.06	≤ 0.35
Total	0.19	≤ 0.50
	Fifth intercomparison	
Bias |B|	0.25	≤ 0.30
Standard deviation	0.06	≤ 0.35
Total	0.31	≤ 0.50
	Sixth intercomparison	
Bias |B|	0.09	≤ 0.30
Standard deviation	0.08	≤ 0.35
Total	0.17	≤ 0.50

The Bias (B) in sixth test was found to be 0.09 compared to the acceptance limit of less than or equal to 0.30. The Standard Deviation was 0.08 ; accepted limit less than or equal to 0.35. Finally the sum of the both the parameter is 0.17; compared to the accepted limit less than or equal to 0.50. The evaluation of the quality control tests evidently shows the gradual improvements of our TLD measurements. A gradual improvement of dosimetric assessment can be seen from the compiled results and thereby contributed further to the reliability of our TL dosimetry service as well as the procedures followed. Negligible loss of sensitivity and signal fading over 90 days were observed in the process. The KACST certified that the TLD results succeeded the National Standard Quality Control Checks in the Kingdom of Saudi Arabia and hence certified to provide personnel TLD dosimetry services.

CONCLUSION

A 'Standard Annealing Procedure' has been established for TLD readout. The relationship between TL signal and the duration of the pre-readout annealing demonstrates that 10 minutes to be the most appropriate preheat time. The standard TLD technique is characterized by harmonized TLD signal, much better accuracy, and high precession radiation dose measurements applicable to beta and gamma radiation types. The annealing procedure at 400 ^{0}C for 1 h, 100 ^{0}C for 2hrs and 100 ^{0}C pre-readout for 10 min may be treated as the 'Standard Annealing Procedure' adequate enough to stabilize the TLD sensitivity to radiation without significant loss of signals. It has been observed that the group sorting results in improving the precision of TLD measurement. PTW UNIDOS dosemaster coupled with PTW 10000 cc ionization chamber apparently improved the DCF significantly. Comparison between measured and reference doses at Cs-137 standard calibrator at different distances using two dosemasters, a significant improvement in relative error (-1.43%) between the reference dose and the UNIDOS measured dose has been observed. Intercomparison program with SSDL facility through the National Regulatory Authority, King Abdulaziz City of Science and Technology, has been successfully accomplished succeeding the National Standard Quality Control checks.

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