PERSONAL RADIATION DETECTOR γ-TRACER GT2-1 WITH CdZnTe DETECTOR

S. Gushchin, V. Ivanov, A. Loutchanski, V. Ogorodniks

ZRF RITEC SIA, Riga, LATVIA

Abstract. *Personal Radiation Detector (PRD) γ-Tracer GT2-1 had been developed with focus on gamma-radiation detection, search and gamma-radiation source localization function, enhanced PRD features and isotope energy pattern analysis. The device complies general requirements and includes all regular PRD class device features as well as supplementary modes as Multi-Channel Scaling (MCS), Spectrometer, Librarian driven analysis and Data Log recorder. The GT2-1 uses detector module build around 0.4 cm³ counting grade planar CdZnTe detector.*

Choice of CdZnTe brings high efficiency of gamma-radiation registration and low energy discrimination level down to 30 keV while volume used is small. GT2-1 is made with power consumption in mind, typical lifetime after full battery charge exceed 600 hours in a measurements mode.

Energy compensation techniques are employed for dose rate calculation. Typical accuracy in the energy range of 30–1500 KeV is better then 10% for factory calibrated devices.

GT2-1 is featuring librarian driven isotope identification function. Basic concept is use of library of pre-calibrated user-defined isotope patterns being compared with isotope under test. Identification algorithm is made to evaluate isotope energy pattern match. Algorithm execution results in tested isotope and library match and results indication in graphical form.

The device search mode employs proprietary Background Variation Tracking (BVT) algorithm. Implemented search and gamma-radiation source localization mechanisms facilitate the user in fast (1–3 sec) detection of weak gamma-radiation sources with intensity in 1.5–3 times exceeding the background level. Analysis of time intervals between adjacent pulses in the input sequence is used to yield numeric characteristics that further displayed in user-friendly graphical form. Dedicated GUI approach and sound capabilities are tailored to search activity flow and aimed to gain operator experience.

Dedicated Search algorithm implementation allows to use the device as a home land security detector by services responsible for radioactive materials relocation control like those in the airports, border control, toll, etc.

Test results of GT2-1 in Search mode are presented.

Key words: *Personal Radiation Detector, PRD, CdZnTe detector, dose rate, dosimeter*

1. INTRODUCTION

Nowadays CdZnTe nuclear radiation detectors of various designs and sizes are widely and successfully used for various applications due to their favorable detection properties – possibility of operating at room temperatures, high efficiency, good energy resolution, small dimensions and weight. There are different devices based on these detectors application, starting from a rather simple detection probes that consist of a detector and preamplifier mounted inside of a common case with spectroscopy measuring systems. Among a wide variety of devices with CdZnTe detectors there are compact pocketsize devices for detection and measuring parameters of gamma radiation. Such instruments of individual application can be used in a wide range of tasks of operative radiation monitoring by first responders – fire, police, rescue workers, liquidators of incidents with nuclear materials, as well as medical staff and personnel of nuclear facilities associated with use of radioactive materials, border monitoring and homeland security. Increased level of terrorist threats makes wide use of such devices for fast, accurate and reliable detection of illicit trafficking of nuclear materials more relevant.

Conventionally, such devices are divided into several groups differing in their purpose. These are Personal Radiation Detectors (PRD), dosimeters, Spectral Personal Radiation Detectors (SPRD) or Radiation Identifiers.

The PRD primary task is radiation detection, alarm generation in case of possible radiation threat to the operator or source presence indication. Modern PRD is a hand-held lightweight tool kept in the pocket or fixed on a wearer's belt. Well-designed PRD must be fast enough to react on short-term radiation surges while good sensitivity tool is attributed by lower relevant level of radiation field increase registered and reported. Essential feature in the modern PRD is visual indication of the radiation related parameters like present dose rate, accumulated dose and alarms.

Inherent ability to register dose rate turns PRD to dosimeter – device that serves to accurately measure dose rate and accumulated dose that the wearer received during exposure period. Therefore radiation sensor used in the PRD and additional techniques must assure energy compensated registration.

Instrument that is capable to register and distinguish radiation emission energies is referred to as the identifier tool. Its general purpose is isotope presence detection. This is based on the fact that radioisotopes have non-similar response in the detector material originating from different energies in their spectra. Unique isotope "signatures" is a function used for their identification based on known energy distribution models.

Existing commercially available devices generally made on the basis of Geiger-Mueller counters or scintillation detectors mainly as NaI or CsI. The main disadvantage of the devices with Geiger–Müller counters is their low registration efficiency of gamma radiation, and devices with scintillation detectors have a relatively narrow range of dose rates of detected radiation, a relatively large size and low mechanical robustness. Usage of CdZnTe detectors allows achievement of sufficient for most tasks detection efficiency and extends measurements of applicable dose rate range. Low threshold of registered energies starts from 20–30 keV.

Currently available SPRD with CdZnTe detectors allow identification of radioactive materials by their gamma-radiation spectra [1, 2]. Spectrometric detectors of various designs with sensitive volumes of 0.5–1.0 cm^3 are used in these devices. These relatively large volume spectrometric CdZnTe detectors are expensive. Cost add-on for these devices grow significantly due to detectors complexity. Therefore, the use of these devices, despite of their high spectrometric performance is still limited.

CdZnTe detectors have several features that need to be taken into account for their successful application. First of all it is the strong dependence of the detection efficiency on energy of detected gamma-radiation and problem of the tissue equivalence of CdZnTe detectors [3–6]. It requires the use of a special energy compensated technique for correct dose rate evaluation. Also a strong microphone effect in the CdZnTe detectors due to its piezoelectric sensitivity must be taken into account. All this restricts and complicates the use of CdZnTe detectors in PRD and dosimeters for field applications.

Research efforts resulted in successful solution of these problems and implementation in commercially available GT2-1. The device integrates the properties of PRDs, personal dosimeters and limited capabilities radiation identifiers. The GT2-1 is made on the basis of a relatively cheap "counting" grade CdZnTe detector of planar geometry and volume of 0.4 cm^3. A special feature of this device is its Search Mode for detection, search and localization of gamma-radiation sources. True Dose Rate measurement requires energy compensation of the detection efficiency. Applied compensation method uses information about spectral composition of the detected radiation.

In this paper descriptions of the device, main features, main operating modes, signal processing algorithms and test results are given.

Fig. 1 Personal Radiation Detector GT2-1

2. GT2-1 MAIN FEATURES AND MODES DESCRIPTIONS

Personal Radiation Detector GT2-1 is pocketsize lightweight gamma and x-ray radiation measurement instrument build on solid-state CdZnTe detector. The device is made to combine proven measurement characteristics, rich set of functions and features and use of benefits granted by last semiconductor technology achievements. Affordable price, free PC tools and long time of continuous operation without recharging let user to have professional class tool with moderate impact on budget. GT2-1 features professional grade sensitivity (10 cps at 0.01 μSv/h ^{241}Am), wide measuring range (5 decades), response from 30 keV, energy-compensated true dose rate measurement and rich set of additional features. Selection of CdZnTe results in extended dynamic range, enhanced accuracy, perfect linearity within 4 decades, temperature range and time stability [7]. GT2-1 is shown in Fig. 1.

GT2-1 block diagram is represented in Fig. 2.

Detector module (DET & PA) consists of a planar counting grade CdZnTe detector and charge –sensitive preamplifier. Detector dimensions of 2 cm x 1 cm x 0.2 cm is found optimal for sensitivity and budgetary reasons, though another sizes are applicable. Electrical pulses generated in Detector module as result of radiation photon interaction with solid-state detector material further supplied to data acquisition and processor (PHD, CPU). Results are processed by CPU and stored in non-volatile memory (MEM). Run-time processing includes Alarms generation (UI) and controls check (KBD). Device power subsystem comprises high voltage generator and linear drop-down stabilizer (PS) powered by rechargeable Li-ion battery.

This device architecture and use of low-power Cortex M0+ CPU allows long-time battery operation in regular Measurement mode and enables implementation of additional functions attributed to expansive professional tools. Selection of non-spectrometric solid-state CdZnTe detector instead of conventional scintillator or Geiger–Müller counter yields perfect compromise between sensitivity, linearity, and time stability with set of new functions for lower price.

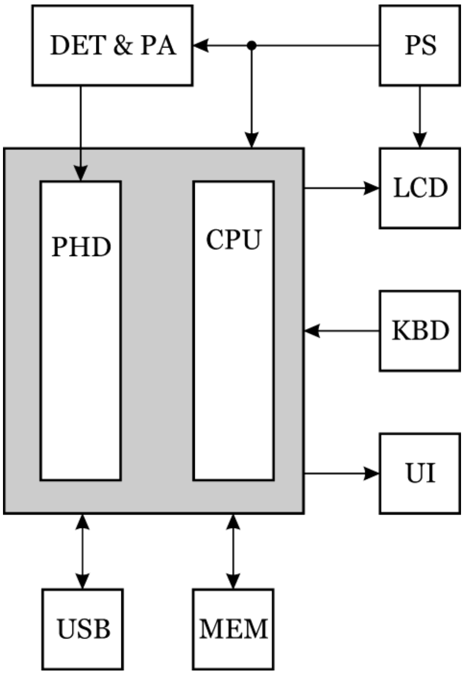

Fig. 2 GT2-1 block diagram. DET&PA – detector module, PHD – Pulse Height Discriminators, CPU - Central Processing Unit, PS – Power Supply, LCD - Liquid-Crystal Display, KBD – keyboard, UI – User Interface (LED, buzzer, vibration motor), MEM - non-volatile memory, USB - Universal Serial Bus driver

Dose rate calculation with energy compensation for non-spectrometric CdZnTe detectors address techniques suggested in paper [6]. Key advantage of this technique is estimation of power distribution across seven preset energy ranges and analytic calculation of dose rate using polynomial coefficients.

Dedicated Search Mode is implemented to facilitate detecting and localizing artificial radiation sources.

Spectrum Match analysis of gamma ray spectra is optional tool available as dedicated mode in the GT2-1 to facilitate isotope identification based on results of previous learning procedures.

Three acquisition modes address various operation conditions and made to tailor intrinsic algorithm parameters to particular measurement conditions. These are Accuracy, Balanced and Response. Accuracy mode attributed by greater integration time constants, Response better suit for device operation in relatively high changing radiation fields. Balanced is default mode with levered parameters.

GT2-1 in Measurement mode supports either Dose Rate or Count Rate indication. All acquired results are stored in non-volatile memory and may be reached as logs read with GT2 Configurator PC software, browsed and converted to spreadsheet format.

Alarm subsystem process both Dose rate and Count rate run-time checks while GT2-1 is in Measurement Mode. Alarm signalization functions include sound (audible and earphones), two color LED's, vibrator.

On a par with regular mechanical countermeasures GT2-1 introduce detector condition supervisor firmware block to depress microphonic effect and to avoid magnetic fields influence.

In the Multichannel Scaling mode the count rate of registered pulses as a function of time is recorded. Both Dose and Count rates indication supported.

All essential parameters can be quickly accessed via Quick Set Menu and Main Menu options while full set of run-time parameters may be modified using free PC software tool GT2 Configurator.

3. Search Mode algorithm

Search mode implementation associated with nuclear instruments is not straight forward task for implementation due to need to process a number of signals in real time while computation and power resources of battery powered PRD are limited. Particular challenge is inherent stochastic nature of signals and due intensive statistical math methods involved for search criterion evaluation.

Regular search methods based on count rate variations suit best for devices with large detector volume. It is not feasible for portable devices due to size, weight and budgetary reasons. New method based on timing analysis had been adopted and tested. Key assumption that drives implementation is tolerance to fault detection rate being notably higher than that of regular measurement mode. Tailored visualization techniques are introduced to ease operator-searching practice as well as improve fault detection to missed detection ratio for weak sources.

Introduced in GT2-1 dedicated Search mode is build on proprietary Background Variation Tracking (BVT) algorithm. Device in this mode focus on detecting and localizing activity and offers the operator intuitive visual tool to enable the operator reliably find source of artificial radiation. Effective natural background variation suppression algorithm employs static period distribution model and actual learning results. Operator has option to manually select sensitivity grade thus finding tradeoff between sensitivity and fault detection rate.

Key math principle behind Search mode operation is moving average [8] inter-pulse period estimation and following statistical processing. Run-time acquisition results history is allocated in volatile memory tables. Two vertical bars reflect results of input count rate analysis and BVT algorithm processing. Fast response channel relate to operator movements and indicates direction, while Slow response channel relate to proximity of the active source (see Fig. 3.). Some preliminary training exercise and practice are required. Particular algorithm parameters originate from field tests conducted with

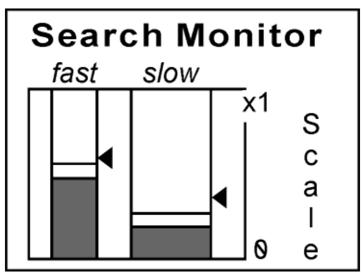

Fig. 3 Search Mode monitor window

several persons and evaluated from best results. In order two addresses wide range of possible initial background levels the system has intended manual controls – buttons Scale Up and Scale Down. Note that GT2-1 in Search mode automatically adapts integration time when input count rate increase.

4. Spectrum Match Mode and Isotope ID

Budgetary requirements drive PRD vendors to use rather low volume "counting grade" detectors. This limitation makes implementation of spectrum classification modes complicated since available spectra with poor statistics and resolution lack required information. However, definite spectrum processing techniques allow isotope evaluation with relaxed time constrains and limited set of reliably and simultaneously distinguished isotopes [7]. Modified approach implemented in GT2-1 realizes spectrum comparison with weighting coefficients. Method implementation as dedicated device mode brings the user more flexibility for nuclide identification practice. As a result of investigation GT2-1 introduce proprietary low resource radionuclide identification algorithm for certain number of isotopes or mixes based on seven channels region of interests (ROI) information. Effective background elimination assures 20–2000 cps of detected isotope input count rate and significantly increase method sensitivity.

The key principle behind this approach, in contrast to offered in [7], is comparison of corresponding ROI ratios of adjacent channels and use of intended background compensation process calculating compensation count based on average inter-pulse period for each ROI channel. This combination result in improved isotope spectra match level though involves more preparation steps and careful calibration to assure acceptable confidence level.

Typical scenario to be followed starts from laboratory preparation: background calibration and reference isotope calibration for each isotope type (or mix) used in the following ID analysis. Identification operation depends on due user libraries and their quality. Therefore a library of reference spectra for a certain GT2-1 device needs to be collected by the operator beforehand.

In general, not only sole isotope but also random mix of isotopes can be taken for library calibration. There are four isolated locations in the GT2-1 non-volatile memory intended for mixes or unknown isotopes referred to as X1 – X4 in the system menu. While GT2-1 is in identification mode spectrum under test first qualified as one of three classes – low, middle and high energy. This is needed to increase evaluation speed and generates helpful identification criteria. At the second stage-collected spectra repeatedly compared with all active library entries and isotope-tailored weighting coefficients (factory defaults) are applied to emphasize spectrum peculiarities. Ultimate results of comparison then passed to statistical processing that yields correlation values proportional to matching levels. The reference spectrum for which the best correlation is found is the detected isotope type being indicated on the display. Another supplementary output information informs the operator on relevant match grade in percent, current

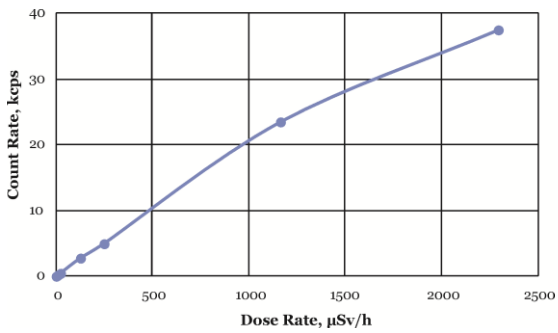

Fig. 4 Measured count rate versus dose rate

count rate applicability and volume of collected statistics used for acquisition.

Spectrum Match mode implementation in GT2-1 is not full feature reliable tool with obvious limitations imposed by used detector resolution. However, it may be reasonable compromise for users dealing with certain number of known isotope types and budgetary constraints.

5. Test results

GT2-1 accuracy certification had been carried in the certified Secondary Standard Dosimetry Laboratory (Salaspils, Latvia). Calibration procedure had been fulfilled at radiation test facility with panoramic gamma irradiator capable to output 0.9–2300 µSv/h at ^{137}Cs and 6.6–160 µSv/h at ^{60}Co.

Tests shown good accuracy for dose rate measurement at ^{137}Cs source in the measured range of 0.9–890 µSv/h and at ^{60}Co source in the measured range of 12–155 µSv/h. Typical accuracy of factory calibrated devices was within 8% for 3 decades of load variation for both isotope types.

Fig. 4 shows dependence of a registered count rate on dose rates at points of measurement with ^{137}Cs source. A good linearity of a measured count rate in a dose rate range up to 1500 µSv/h was observed.

To systematize testing and verification of the GT2-1 search capabilities measuring test setup had been constructed. Schematic test setup diagram is demonstrated in Fig. 5. Source of gamma-radiation (^{137}Cs, activity 60 kBq) was allocated at the moving holder (1). Holder is engaged with reciprocating mechanism (2) controlled by a control unit (3). Radiation source in the holder can move between two

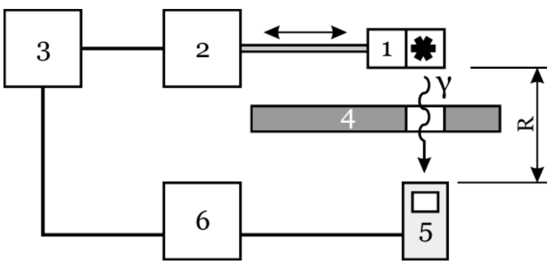

Fig. 5 Schematic test setup: 1 – gamma-radiation source ^{137}Cs mounted in a holder, 2 – reciprocating motion mechanism, 3 – control unit, 4 – lead shield, 5 – PRD GT2-1, 6 – Personal Computer.

positions and stop at one of the positions as follows: hidden behind of 50 mm lead shield (4) or set in front of slit spot of 50 mm width (source radiate to the GT2-1 (5) through the slit). Source movement speed was around 0.1 m/sec. As the source moved the device exposure didn't appear immediately. Dose rate level rise time was within 0.15–0.2 sec. Control unit allows for measurement of time interval when source is behind the shield and in engaged position. Number of basic tests in a trial can be assigned and controlled through Control Unit setup. Required irradiated dose rate at the point of interest is adjusted changing distance R between the source and the GT2-1. In the tests we commit observation at dose rate levels from natural background 0.10 µSv/h up to five times (based on averaged count rates ratio) above the background level. Count rate registered by the tool at background level was about 2 cps (^{137}Cs).

Each basic test consists of the following steps: source moved to the slit, standing in front of the slit (radiation exposure position) and return back behind the lead shield. Therefore the device is exposed to radiation field for the time period T and preset dose rate level (1,5, 2, 3 and 5 times above the background level). We used series of basic tests to get required statistical information in our trial. Every trial sequence comprises 100 identical basic steps. During the basic test the device can either detect the source or not. In both situations result is sent to PC collecting statistical information. For each test series, the numbers of successful detections of the sources as percentage of total number of the basic tests in the series were counted.

Radiation exposure period varied from 0.65 to 7 seconds for different trials. We have had a chance to test different operation modes of GT2-1, get relevant numerical values and compare them with parameters of another detecting tools in the same test installation. All tools as well as supplementary measurement probes were subject to identical reference points with required gamma radiation intensity. The devices were placed at the reference point the way the geometric center of the detector coincide with the point.

Numeric estimation of the false warning rate when source is absent was made. Such signals appearance frequency was around 2 signals per minute when Search Mode scale 1 set and less then 1 signal per minute with scale set to 2. False detection basically connected with background statistical variations.

Additionally were made comparison test of the GT2-1 working in Search Mode with device build on scintillator CsI detector of volume 3 cm^3 working in regular measurement mode with background surplus signals turned on. Also trial sequence of 100 basic tests was made and number of warning signals was registered.

Fig. 6 shows the dependence of the number of successful detections of the source in percent on the radiation exposure period for various dose rate levels. Performed measurements showed that in the search mode scale 1 the GT2-1 provides about 70% of successful detections of presence of a weak radiation source ^{137}Cs creates the dose rate at the point of measurement about 0.15 µSv/h (x1.5 background) for the exposure period of 6–7 seconds. For comparison, on the same figure the results of measurement

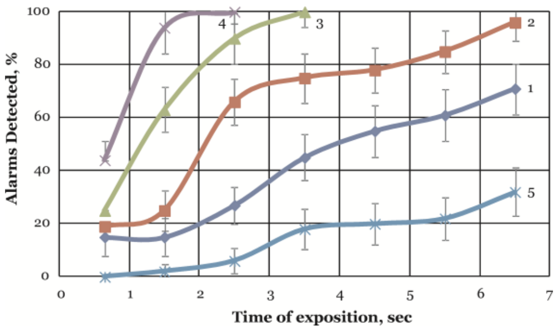

Fig. 6 Number of successful detections in percent on the radiation exposure time for dose rate: 1 – 0.15 µSv/h (1.5 times above the background), 2 – 0.2 µSv/h (2 times above the background), 3 – 0.3 µSv/h (3 times above the background), 4 – 0.5 µSv/h (5 times above the background), 5 – measurements with scintillator detector of 3 cm^3 for dose rate 0.15 µSv/h.

obtained when using the device with scintillation CsI detector of 3 cm^3 in volume in the same conditions are shown. Despite the fact that this scintillation detector has much greater detection efficiency (background count rate was about 8 cps), it can detect the same radioactive source for the same exposure period of 6–7 sec only in 25% measurements of total number of basic tests. Sources of gamma-radiation creating higher dose rates were detected by the GT2-1 within much shorter period. Gamma-radiation source with the intensity of 0.20 µSv/h (x2 background) is detected in 70% of cases during the exposure period of 3–4 seconds and with the intensity of 0.50 µSv/h (x5 background) during 1 sec. 100% detection signals at this intensity was obtained within 2 seconds.

6. Conclusions

Pocket-size Personal Radiation Detector GT2-1 based on application of the planar “counting grade” CdZnTe detector with the function of gamma-radiation dosimetry was developed and is commercially available. The GT2-1 is specifically focused on the detection, search and localization of gamma-radiation sources.

Used a relatively small volume CdZnTe detector of 0.4 cm^3 and implemented proprietary original Search algorithm allows detection of weak radiation sources within rather short periods. Thus, gamma-radiation produced in a point of measurement dose rate about of 0.20–0.30 µSv/h can be detected in 2–3 seconds.

Device operation in the Isotope ID mode using modified low resource radionuclide identification algorithm allows identification of certain isotopes pre-defined in the device memory.

Future trends in the development of GT series of PRD elaborate integration of a small-size spectrometric CdZnTe detector and large volume counting detector to extend dynamic range of the (applicable) registered dose rates and to approach the isotope identification capability to that of expansive professional systems.

REFERENCES

1. Spectroscopic personal radiation detector identiFINDER R300, FLIR Data Sheets, http://www.flir.com/uploadedFiles/flirGS/Threat_Detection/Radiation_Detection/Products/IdenitiFINDER-R300/DS_identiFINDER-R-300-en.pdf.
2. Spectrometric Personal Radiation Detector GalaxRay, Galaxray Data Sheets, http://www.galaxray.com/products.html#tabs-tab-title-2.
3. V. Nagarkar, M. Squillante, G. Entine, I. Stern, D. Sharif, CdTe detectors in nuclear radiation dosimetry, NIM, A 322, pp. 623–627, 1992.
4. В. С. Горев, В. А. Кожемякин, О. А.Матвеев, М.Д.Фирсов, А. Х Хусаинов, Г. К. Шульгович. Применение детекторов на основе теллурида кадмия в дозиметрии гамма-излучения, Приборы и техника Эксперимента, No. 1, pp. 60–64, 1981.
5. В. А. Мокрицкий, О.В. Маслов, О. В. Банзак, Коррекция зависимости чувствительности CdZnTe-детектора от энергии гамма-излучения, Збірник науковыхпраць Військового інституту Київського національного університету імені Тараса шевченко, No. 39, pp. 81–84, 2013.
6. Rybka A. V., Davydov L. N., Shlyakhov I. N., Kutny V. E., Prokhoretz I. M., Kutny D. V., Orobinsky A. N., Gamma-radiation dosimetry with semiconductor CdTe and CdZnTe detectors, NIM, A 531, pp. 147–156, 2004.
7. Arlt, R. Brutscher, J. ; Gunnink, R. ; Ivanov, V. ; Parnham, K. ; Soldner, S.A. ; Stein, J. Use of CdZnTe detectors in hand-held and portable isotope identifiers to detect illicit trafficking of nuclear material and radioactive sources. Nuclear Science Symposium Conference Record, pp. 418–424, 2000 IEEE.
8. http://www.maths.qmul.ac.uk/~bb/TS_Chapter4_3&4.pdf.