# Saving lives through early detection: Breaking the PET efficiency barrier with the 3D-CBS

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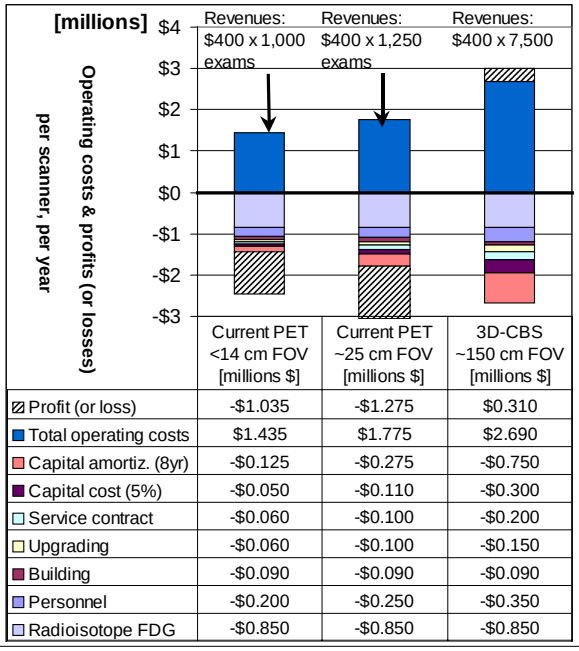
*Abstract*

**An innovative 3-D Complete-Body-Scan (3D-CBS) medical imaging device, combining the benefits of functional imaging capability of the Positron Emission Tomography (PET) with anatomical imaging capability of the Computed Tomography (CT), is presented. The unique architecture of the 3D-CBS electronics allows for the extension, in a cost-effective manner, of the axial field of view (FOV, which is the length of the detector) to over one meter in length. The 3D-CBS captures about 1,000 out of 10,000 photons in time coincidence, compared to only 2 out of 10,000 captured by the best current PET. In addition, the overall architecture of the 3D-CBS permits the use of a single detection apparatus without moving the patient or the detector during a whole-body PET scan. The 3D-CBS features significant improvements in the scanning speed by providing PET and CT exams combined in 2-4 minutes. It achieves increased resolution and accuracy, which provides better imaging with a reduction in "false positives" and "false negatives" and allows a reduced radiation dosage to the patient (1/30th of the radiation dose required by the existing PET). The faster scanning time allows for examinations of at least six times as many PET patients per day with a five-fold increase in net revenues at an examination cost floor as low as $300 (currently the price of a PET scan is $2,000-$4,000). The lower examination cost and higher imaging quality of the 3D-CBS will compete with the cost and quality of current diagnostic workups of CT and PET. The low radiation dosage requirements will open the door to new applications by permitting annual whole-body screening for early detection of cancer and other systemic anomalies (heart function, blood flow, brain activity, metabolic activity). The 3D-CBS will replace in one examination many other procedures of partial cancer screening (prostate, lung, breast, uterus, colon, lymphoma, melanoma, etc.) because it is faster, less expensive, more accurate and less invasive. The best current PETs are based on fast LSO crystals, of which there is a limited production capability. The proposed 3D-CBS device, on the other hand, makes it possible to achieve improved performance now, while using cheaper, slower BGO, CsI crystals, which are currently available in abundance. The need for the 3D-CBS is apparent after analyzing the number of people in a high-death-rate group (i.e., from 45-64 years old, which is still below life expectancy) who are lost, not because the drugs to cure the disease do not exist, but because the instrumentation for early detection of the disease does not exist. Cancer and heart disease are responsible for 60% of the deaths in the 45-64 age range. Clearly, a great proportion of these deaths can be avoided through early detection and treatment. Effective treatments are available; however, without a diagnosis of the disease at a treatable stage, existing drugs and other treatments cannot be used in a timely manner. Current expenditures for prescription drugs (excluding those used in hospitals, nursing homes, and by health care practitioners) in the U.S. are $116.9 billion per year and are projected by HCFA to increase to over $360 billion per year by 2010 whereas expenditures for electromedical, diagnostic and irradiation equipment total only $13 billion per year. It is obvious that one would expect that the impact, in terms of reduced mortality and in terms of global heath care savings, would be immense if diseases were detected while still treatable with improved diagnostic imaging. This will reduce global health care costs by helping hospitals and physicians to select the most effective drug, monitor its effect, and by reducing the cost related to morbidity. The 3D-CBS will also facilitate the development and testing of new drugs. Comparisons of the U.S. national health care expenditures (NHE) as a share of the gross domestic product (GDP) and the NHE/GDP of other countries are provided. Currently, PET imaging efficiency improves 2- to 3-fold every 5 years. A careful analysis of the 3D-CBS project, which increases efficiency over 400-fold compared to current technology, will show that all parties (investors, hospitals, physicians, drug researchers, insurance companies, the government, and patients) will benefit from the implementation of this technology as soon as possible.**

## 1 INTRODUCTION

Figure 1 and Table I show general characteristics and cost comparisons of the current PET and the 3D-CBS [1], [2], [3].

TABLE I. COMPARISON OF THE OPERATING COSTS PER SCANNER PER YEAR WHEN USED FOR THE SAME NUMBER OF HOURS PER DAY, AT THEIR HIGH THROUGHPUT AT A PRICE OF $400/EXAM. (SOURCE: RADIOISOTOPE MANUFACTURERS, HOSPITALS ADMINISTRATION FOR USA AND TABLE 5-1 OF [4] FOR EUROPEAN COSTS).




| | Current PET <14 cm FOV [millions $] | Current PET ~25 cm FOV [millions $] | 3D-CBS ~150 cm FOV [millions $] |
|---|---|---|---|
| Profit (or loss) | -$1.035 | -$1.275 | $0.310 |
| Total operating costs | $1.435 | $1.775 | $2.690 |
| Capital amortiz. (8yr) | -$0.125 | -$0.275 | -$0.750 |
| Capital cost (5%) | -$0.050 | -$0.110 | -$0.300 |
| Service contract | -$0.060 | -$0.100 | -$0.200 |
| Upgrading | -$0.060 | -$0.100 | -$0.150 |
| Building | -$0.090 | -$0.090 | -$0.090 |
| Personnel | -$0.200 | -$0.250 | -$0.350 |
| Radioisotope FDG | -$0.850 | -$0.850 | -$0.850 |

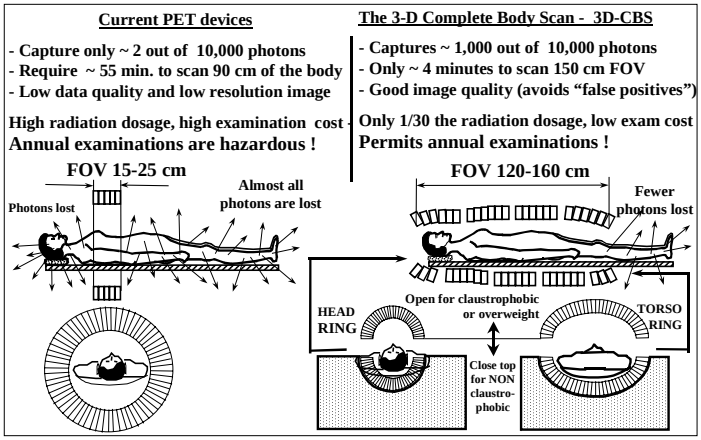



**Figure 1. Differences between the current PETs and 3D-CBS.**

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A common question arising from a description of the 3D-CBS is "How much does the machine cost?" The person asking the question is discouraged to hear that it costs more than the current PET. However, the focus should be on the cost per examination, not the cost per machine. For example, when a person needs to go from France to England (or *vice versa*), he or she does not ask how much the tunnel under the Channel costs, but rather he asks how much a ticket to cross the Channel costs. (A row boat would cost less than a tunnel project costing billions of dollars; however, the tunnel has obvious advantages that make it worth building). In the case of medical imaging, it is hoped that the 3D-CBS will, as did the CT[1] [5], [6] some twenty years ago, surmount the initial resistance against it and come to be recognized as an effective tool in the fight against cancer and heart disease.

Figure 2 shows the comparison of the scanning time between a current ~25 cm axial FOV PET and a ~150 cm axial FOV 3D-CBS.

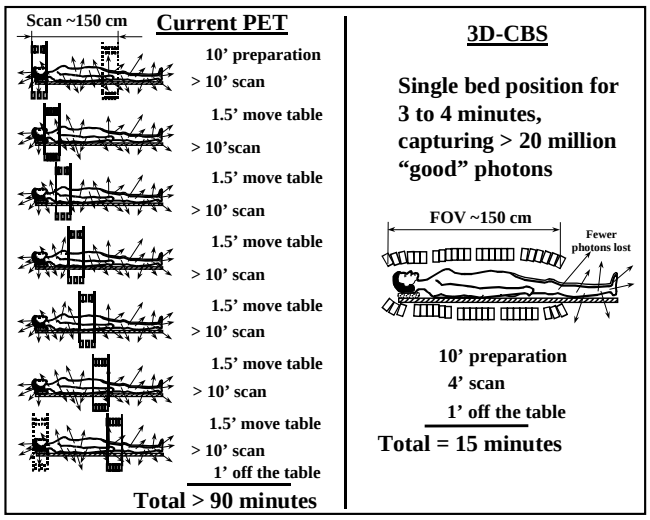


**Figure 2. The current PET (figure at left) with short (< 25 cm) axial FOV (the length of the detector) requires ≥ 7 scanning table positions,[2] each longer than 10 minutes, to cover about 150 cm of the body and record more than 20 million data of photons in time coincidence. The 3D-CBS (figure at right) with a longer axial FOV (~150 cm) and with more efficient electronics, can capture > 20 million data from photons in time coincidence in < 4 minutes.**

The purpose of this article is to show how the technological advances of the 3D-CBS diagnostic imaging machine can save more lives and improve the quality of life and life expectancy in a cost-effective manner through early detection of health anomalies. The aim of the author is to provide a tool with a low radiation requirement that uses material available in the world in abundance for providing a life-saving medical procedure at low, affordable cost to many people. During 1999, drug expenditures increased by 19% over 1998; however, measurements of additional lives saved did not show a great reduction in the death rate compared to the previous years. To the degree that we can assume a direct correlation, the effort was not cost-effective (see Figure 3 and Table X). The combination of the new, improved drugs and the 3D-CBS diagnostic imaging capable of giving the physician a means of measuring the effects of new drugs will optimize the use of drugs and reduce their cost, totaling to a more cost-effective result. To the end of reaching these goals, this article provides (a) a study of the social impact of the introduction of this new 3D-CBS device (see Sections 1, 2, 3, 8, 9, 11, 12, and 13), (b) an analysis of its economic impact in health care (See Sections 1, 6, 8, 9, 10, 11, 12, 13, and Appendix A), and (c) the basic concepts of the technological advances of the 3D-CBS which provide a better image quality at lower a radiation dose[19] and lower cost. (See Sections 3, 4, 5, 7, 13, Appendix B, and C).

The technological issues which are addressed in this article are: (a) the deficiencies of current PET, described in Appendix C.1; (b) how these deficiencies are remedied by the 3D-CBS, described in Appendix C.3; and (c) the distinctive innovative features of the 3D-CBS, described in Appendix C.2.

A detailed analysis of the cost of the entire project and its improvement in efficiency compared to historical data [1], [2] should answer any questions about its cost-effectiveness.

During the past 20 years the focus of the designers of PET devices has been on improvement of the crystal detectors. For about 15 years, the fast lutetium orthosilicate (LSO) crystals, which are nearly ideal[3]; have been available; however, the world-wide production capability[6] of LSO is still far from what would be necessary for a development plan such as the one proposed in this article.

The efficiency increase[4] in one giant step of the 3D-CBS (see Section 4), even when slow crystals are used, opens the

[1] Several experts in the field such as the president of RSNA, Dr. Robert Parker, have facts [5] showing that a more expensive machine (such as the CT scanner) reduced health care costs and improved the patient's care. Statistics show that imaging equipment is not the driving cost of health care. AK Dixon et al. showed as early as in 1987 that the cost of treatment and diagnosis can be reduced considerably using whole-body CT (see reference [6]). The number of CT units per million inhabitants is the highest in Japan with 68 machines compared to 29 in USA, however health care costs per capita are lower in Japan compared to USA (see Table XVII). Perhaps we should consider whether increasing our investment in imaging technology would reduce the cost of health care.

[2] Although someone might claim that one could scan a shorter axial FOV, it is not in the patient's best interest to do so, because once he has received a radiation dose (which spreads over the entire body), it is best for him to get the maximum coverage of disease searches on the entire body.

[3] An ideal scintillating crystal should not be hygroscopic and would have the speed of the Barium Fluoride ($BaF_2$), the density of Bismuth germanium (BGO) and the light of thallium-activated Sodium Iodide (NaI(Tl)), yttrium orthosilicate (YSO), or cesium Iodide (CsI). Lutetium orthosilicate (LSO) is nearly to ideal and has been incorporated in the most recent PETs. However, the search of economical new material which is dense and has a short decay time (or narrow light pulse) is still underway.

[4] The breakthrough in efficiency of the 3D-CBS, even if slow crystals are used, is achieved through the 3D-Flow architecture of the electronics, which can perform, with zero dead-time, pulse shape analysis with Digital Signal Processing (DSP) on each channel, with correlation with signals from neighboring channels as well as from channels far apart and with improvement of the signal-to-noise ratio (S/N) before adding them. In addition, the unique architecture of the electronics can accurately determine the photon's arrival time, resolve pile-up, perform several measurements requiring complex calculations (depth of interaction, clustering, signal interpolation to increase spatial resolution, etc.), and limit the detector dead time to the very small area where the incident photons hit the crystal, rather than a large area of the detector as now occurs with current PET electronics.

door to a whole new area of applications by permitting (a) annual whole-body screenings, (b) the monitoring of the effectiveness of prescribed drugs during diagnostic workups[5] [4], [7], (c) the development of new drugs and the study of their effects, and (d) its use in an emergency room. (See also Section 9).

If LSO crystal becomes more readily available[6] or less expensive in the future, the design of the 3D-CBS can accommodate for these fast crystal detectors as well by simply loading a different program (real-time pattern recognition algorithm) in the 3D-Flow processors program memory. However, slow crystals such BGO, CsI, available in abundance now, can be used with the 3D-CBS. (See Appendix C.2).

The example described in this article considers only the U.S. market, which is presently less than 1/3 the world market for medical imaging and this market is expected to achieve only one quarter of the scans for diagnostic workups (currently done by CT in the U.S. See Table XIV) by the year 2010 and to screen only 15% of the U.S. population over 50 (see Table VIII). (This estimate is very conservative compare to the 60% projected market by Dr. Wagner[7]) However, even this limited market would require about 3,000 3D-CBS scanners in the U.S. by 2010 (see Table IV and Table VIII).

A very conservative estimate of the 3D-CBS diagnostic workup (see Table V) and cancer screening (see Table VII) market is about $5 billion per year by the year 2010 in the U.S. If Dr. Wagner's projection[7] is considered, the market will more than double, and if we consider the world-wide market (using Dr. Wagner's projection), the market could be over $50 billion per year by 2010. (See Section 11).

Although these figures seem high, they are low when one considers (a) overall health care expenditures, (b) the benefits of the new technology in lives saved, and (c) the savings in the cost of other procedures (see Table XI) avoided because of the superior imaging of the 3D-CBS diagnostic device. To illustrate, the projected annual $2.46 billion expense by the year 2000 for diagnostic workups using the 3D-CBS is only 0.093% of annual health care expenditures; even when accounting for screening, it will be only 0.189% of U.S. health care expenditures. See Figure 18).

The operating costs of the 3D-CBS shown in Table I include the capital cost of the machine amortized over 8 years, the capital cost of the building where the machine is located (estimate $1 million) amortized over 40 years, the operating cost, including the expenses of the radioisotope[8], the personnel[9], the maintenance[10], and the upgrades.[11]

For purposes of comparison, let us use an examination price of $400. At this price, the revenues per year of the current PET with about 25 cm axial FOV (see left side of Figure 2) are calculated based on a quantity slightly above the average[12] [8] (about 1,250/year, or 5/day) as 1,250 x $400 =$500,000 per year. Because of the expenses of $1.75 million per year, the current PET would show a loss of about $1.27 million per year. (This explains why the current PET exam cost is between $2,000 and $4,000. See Section 8).

The current PET with a shorter axial FOV (< 14 cm) would entail a lower expense than the PET with about 25 cm axial FOV; however, because it is also slower than the 3D-CBS, it can perform even fewer examinations (about 1,000/year, or 4/day). The loss, therefore, will still be about $1 million per year.

Conversely, the 3D-CBS with about 150 cm axial FOV (see right side of Figure 2) can perform more examinations (about 7,500/year, or 30/day), providing a net revenue of

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5 Two recent works on PET imaging in oncology are the book [4] and the article [7] with over 300 references.

6 In order to achieve the very conservative projection of about 3,000 3D-CBS scanners by 2010, approximately 150 $m^3$ of scintillating crystals (see calculation in Section 11) will be needed during the next 9 years just for the U.S. market, and over 500 $m^3$ would be needed if the world-wide market would be considered. Because during the past fifteen years the overall worldwide production of fast LSO crystals was less than 5 $m^3$, it is difficult to imagine that the production capability for LSO crystals could increase to 500 $m^3$ during the next nine years.

7 Dr. Henry Wagner, one of the founders of nuclear medicine, made the following prediction at the 2000 meeting of the Society of Nuclear Medicine: "Within five to 10 years, 60% of all imaging studies will be fused images." The term "fused" refers to multimodality, such as PET combined with CT, or functional and anatomical imaging. However, there is a substantial difference between the current PET/CT units manufactured recently and the 3D-CBS. The current PET/CT machines consist of two units placed side-by-side, still have most of the problems of the current PET machines (these two separate scanners do not eliminate the motion of the patient's table which generates motion artifacts in the image, requires high radiation, provides low throughput with limited quality of the images, and has a slow scanning time), and further diminish the cost-effectiveness because the fast CT scanner (4 to 10 minutes) is limited by the slow PET scanner (50-90 minutes). This limits the overall throughput and increases the examination cost. Conversely, the new 3D-CBS has the two units (CT and PET) intrinsically built in a single detector which detects both photons (CT x-rays and PET γ-rays). This requires a combined examination time of only 2 to 4 minutes, eliminates the need to move the patient (which completely eliminates the image motion artifacts, blurring, etc.), increases the throughput, and reduces the radiation. In summary, the 3D-CBS device synergizes the efficiencies of the two machines.

8 Radiopharmaceutical costs, as well as building costs, may vary substantially depending on the location; figures in this article are conservative, using the figures toward the highest costs. Although the 3D-CBS will be scanning more patients per day and it will use a lower daily quantity of radioisotope, the daily cost for $^{18}$F-FDG radioisotope has been kept the same for the three scanners ($3,400/day). The cost of the $^{18}$F-FDG is higher in the U.S. compared to Europe. This estimate is based on the higher U.S. cost for the amount of radioisotope needed by a ~25 cm axial FOV PET, which is $3,100 per day for scanning 4 patients/day, $3,400 per day for scanning 5 patients/day, $3,600 for scanning 6 patients/day, and $3,800 per day for scanning 7 patients/day.

9 Personnel costs have been based on Table 5-2 on page 37 of [4]: ½ MD, 2 technologists/administrators for the >14 cm FOV; ½ MD, 2 ½ technologists/administrators for the ~25 cm FOV; 1 MD, 2 ½ technologists/administrators for the 3D-CBS.

10 Annual maintenance costs has been assumed to be $60,000 for the < 14 cm FOV PET, $100,000 for the ~25 cm FOV PET, and $200,000 for the 3D-CBS.

11 Annual costs for the upgrade of the scanners have been assumed to be $60,000 for the < 14 cm FOV PET, $100,000 for the ~25 cm FOV PET, and $150,000 for the 3D-CBS. Because the 3D-CBS has included all possible improvements, the costs for upgrades is relatively low and is mainly due to software upgrade, while for the short FOV PETs there is room for more improvements.

12 See the article in reference [8] reporting that in the year 2000, 250 PET units in the U.S. made over 250,000 examinations.

about $310,000 per year per scanner. This is calculated as $400 x 7,500 exams = $3 million, less $2.690 million of costs.

The 3D-CBS will still be advantageous when used for a lower volume of patients per unit (see Table VI) because it will perform the examinations in fewer days per week, saving radioisotope and personnel costs. Table XII reports a detailed study of the lowest price possible for an examination using 3D-CBS vs. other PET devices. It shows that the 3D-CBS could sustain a $300/examination price (compared to the current average price of $3,000/exam). The winner from the entire process will be the consumer (the patient) who will receive, thanks to the competition, a better examination with a better quality image, requiring lower radiation[19] at about 1/10 of its current cost.

Section 9 shows the main reasons for the need for a technological advance in non-invasive pre-clinical diagnosis.

An action plan and a request for comments and collaboration to hasten the benefits of the 3D-CBS project is requested in Section 14.

## 1.1 The need for imaging devices and drugs

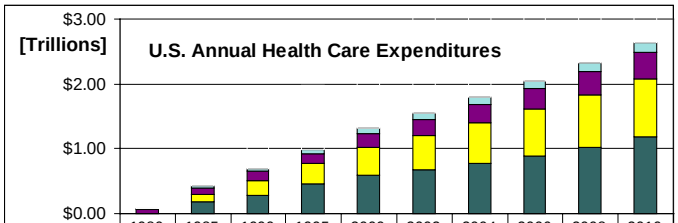
Effective treatments are available and a considerable budget for research on new drugs is also in place; however, without a diagnosis of the disease at a treatable stage, existing drugs and other treatments cannot be optimally effective (see Appendix A.2).

Section 9.2 provides statistical data of the major causes on death among people below the lowest life expectancy and indicates what is necessary to help to defeat cancer and heart diseases.

The historical and projected cost of global health care in the U.S. are shown in Table II, while Figure 3 shows the annual expenditure on prescription drugs for the years 1980-2010 (historical and HCFA's underestimated[13] projected growth) at retail outlets[14] [9], [10] and the expenditure on electromedical imaging[15] [12] devices in the U.S.

Table II details health care expenditures in the U.S. It shows that from 1980 expenditures by health insurance plans increased more than those that were "out-of pocket," and expenditure in this category are projected to more than double by 2010. In 1995 about half of health care costs were paid with public funds, while in 2000, private expenditures increased more than public. The projection by HCFA for 2010 is that private expenditures will be about 25% higher than public expenditures.

**TABLE II. HISTORICAL AND PROJECTED DATA OF U.S. HEALTH EXPENDITURES DURING 1980-2010 (SOURCE: HCFA[17] [9], [10]). SEE ALSO THE U.S. HEALTH CARE EXPENDITURES AS A SHARE OF THE GDP IN TABLE XVI.**




| | 1980 | 1985 | 1990 | 1995 | 2000 | 2002 | 2004 | 2006 | 2008 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|
| Total exp. | $0.08 | $0.43 | $0.70 | $0.99 | $1.31 | $1.54 | $1.79 | $2.05 | $2.33 | $2.64 |
| other priv. | $0.01 | $0.03 | $0.04 | $0.06 | $0.08 | $0.10 | $0.11 | $0.12 | $0.14 | $0.15 |
| Out of pocket | $0.06 | $0.10 | $0.14 | $0.15 | $0.20 | $0.24 | $0.28 | $0.32 | $0.36 | $0.40 |
| Insurance | $0.01 | $0.13 | $0.23 | $0.32 | $0.44 | $0.53 | $0.63 | $0.72 | $0.81 | $0.90 |
| Public | $0.00 | $0.17 | $0.28 | $0.46 | $0.59 | $0.68 | $0.78 | $0.89 | $1.02 | $1.18 |

Although the total cost of health care in the U.S. is increasing every year (however, with a lower increase compared to the increase in the Gross Domestic Product (GDP) during the last three years[16] [11]), advances in technology such as the 3D-CBS can help to keep health care costs lower and improve efficiency[1]. It would be hard to believe that the entire electromedical[15] [12] imaging budget in the U.S. of about of about $13 billion in 1998, or 1.1% of the total health care expenditures (see Figure 18) could be responsible for the increase in the entire health care expenditures. On the other hand, an increase in drug expenditures[17] [11] from 4.9% of the total U.S. health care expenditures (or $12 billion) in 1980, to 8.9% (or $116.9 billion) in 2000, with a projection of 13.9% (or $366 billion) in 2010, should be analyzed to see if drugs are optimally utilized (see Figure 3). The benefits of the 3D-CBS should be obvious because it is proven that replacing many smaller, local machines saves costs in the larger picture by saving unnecessary procedures.[1]

The use of improved medical imaging devices such as the 3D-CBS will also promote the development of new drugs by more accurately monitoring their effect at the anatomical and molecular level and will lower the cost of drugs by providing a timely feed-back on the effect of the drug.

In 1992 HCFA projected that total U.S. health care expenditures would reach $1.7 trillion by the year 2000, an

[13] The growth of prescription drug expenditures in the U.S. of 16.9% in 1999 reported by HCFA in Exhibit 2 of [11] is underestimated because it accounts for only some of the drugs. A more complete analysis by IMS Health in [10] where all prescription drugs in the U.S. in 1999 are considered, shows a growth of 19%. This will further increase the difference in percentage of expenditures in 2010 between drugs and medical imaging with respect to the projected growth shown in Figure 3.

[14] Drug class of expenditure reported by HCFA is limited to spending for products purchased from retail outlets. The value of drugs and other products provided to patients by hospitals (on an inpatient or outpatient basis) and nursing homes, and by health care practitioners as part of a provider contact, are implicit in estimates of spending for those providers' services listed in [9].

[15] Sales of electromedical and irradiation equipment in the U.S., (manufacturing in the U.S., export and import) are available from [12]). The total U.S. electromedical and irradiation equipment manufacturing sales were $6.7 billion in 1990, $9.8 billion in 1995, $13.1 billion in 1998 and $13.9 billion in 1999. During 1998 the following scanners were sold in the U.S., $560,567 CT scanners ($542,644 minus $114,298 export plus $132,221 import); $884,790 ultrasound scanning devices ($1,300,664 minus $497,207 export plus $81,333 import); and $882,606 MRI devices ($842,961 minus $251,647 export plus 291,292 import).

[16] In spite of the title of the article [11], the accurate reporting of the data in the same article shows that Americans spent less (in percentage of the GDP) for health care during 1999 (as well as during 1994 and 1996-1998) compared to the previous years.

[17] Source: U.S. Health Care Financing Administration (HCFA), Office of the Actuary, National Health Statistic Group.

amount equal to 18.1% of the GDP, (and $16 trillion, or 32% of GDP by the year 2030. See Table 7 of [13]). However, the figures reported for 2000 by HCFA in 2001 [11] were $1.3 trillion, or 13.1% of the GDP in the year 2000. Not only were the projections accurate but the actual statistics were better than expected, instead of registering a growth in health care expenditures as a percentage of the GDP, a reduction was registered during the years 1996-1999 (See exhibit 3 of [11], and Table XVI of this document).

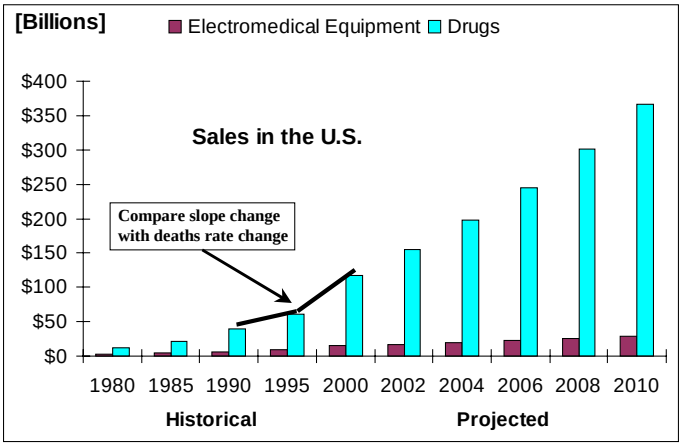



**Figure 3. Annual sales of prescription drugs (historical and HCFA underestimated[14] projected growth) in U.S. from 1980 to 2010 (this excludes those used in hospitals, nursing homes, and by health care practitioners. If all prescription drugs were considered, 20% should be added to the cost. Source[14] [11]) and electromedical equipments (source[15] [12]). See also the percentage of personal health care expenditures for service in categories such as hospitals, dental, etc. in Figure 17 and Table XVIII.**

Although overall health care expenditures as a share of the GDP decreased during the years 1994 and 1996-1999, drug expenditures did not. With the shrinking budget (as a percentage of the GDP), the percentages expended for health care in other categories, such as hospitals and electromedical equipment, were lower. (See Figure 17 and Figure 18)

HCFA health care expenditure projections in 1992 overestimated the increase in overall health care cost but grossly underestimated spending on pharmaceuticals. (See also Table XVIII and [14], [15], [16], [17], [18], [19]).

The projected expenditures for drugs (and medical non-durables[14]), starting at 9.4% in 1991, were estimated (in 1992) by HCFA to be 9.1% in 1992, 8.9% in 1995, 8.3% in 2000, reducing to 7.4% by the year 2010, and 7.2% in 2030 (see Table 8 of [13]). Conversely and unfortunately, the actual expenditures for drugs went in the opposite direction to 10.8% in 1997, and 12.7% in 2000, and are expected[13] by HCFA to be 17% by the year 2010. (These projections can be calculated from exhibit 1 of [11]).

**Improved medical imaging equipment (such as the 3D-CBS, with reduced radiation[19] to the patient) will not only save more lives with early detection of diseases but it will also reduce the cost of prescription drugs by monitoring the efficacy of drugs and providing a tool to utilize them more efficiently.**

## 1.2 Early detection & diagnostic workup

Biochemical processes of the body's tissues are altered in virtually all diseases, and PET detects these changes by identifying areas of abnormal metabolism as indicated by high photon emission. Diagnostic imaging with the 3D-CBS (which combines PET with the CT techniques) will allow for the detection at early stages of cancer and practically all diseases in which abnormal metabolism is signaled by increased radioactivity (See Section 3 which describes the principle of operation of PET machines).

There are two distinct applications for the 3D-CBS imaging device: the one currently used for diagnostic workups in the diagnosis of people with symptoms of cancer or other illness, and the proposed application for preventive care cancer screening, cardiac screening, and monitoring of asymptomatic patients (people who appear to be healthy). See Section 9.

For diagnostic workup, about 30 million Americans[18] received a CT scan during the year 2000 at a price of about $400 to $800 (depending on whether the exam was with or without a contrast agent, or if both exams were required). Using the 3D-CBS, only one exam at a price of about $400 would be necessary: a PET exam with the 3D-CBS using a radioisotope will provide better information than current CT with a contrast agent, and a CT exam within the 3D-CBS will provide an image without a contrast agent because its data can be filtered electronically from PET.

For preventive care research screening, the $300 cost minimum (see Table XII) of the non-invasive 3D-CBS exam offers, in a single exam of 2-4 minutes, a more thorough search for diseases in the whole body at lower risk than some current procedures and it is competitive with (a) the summation of the costs of several current screening procedures regularly reimbursed by health insurance, such as mammograms, pap smears, digital rectal examinations (DRE), prostate specific antigen (PSA) tests, etc., and (b) the summation of the costs of the previous procedures by a larger number of more expensive procedures currently used by the wealthiest, such as colonoscopy, CT scan, etc. (see Table XI).

Sixty percent of deaths in the 45-64 age group are due to cancer and heart disease. Because of the limited screening of people over 50 years of age and the limited scope of organs screened by current procedures, this figure is much higher than it might be with an annual preventive health care screening program. In other words, many of these untimely deaths could be avoided with whole-body preventive screening. A study conducted by the National Cancer Institute determined that cancer alone costs the U.S. $107 billion per year. An annual screening of about 15 million Americans (about 15% of the population over 50) by the year 2010 as shown in Table XIV would cost only about $4.5 billion ($300 x 15 million exams), and would reduce the death rate from cancer and heart disease and reduce health care costs[1].

[18] The number of CT examination in the U.S. is calculated as 2,600 exams per scanner per year (more exams per scanner in the past years. See Table IV for the CT scanners and Table XIV for the projected number of exams in the U.S.). Fewer exams per scanner are performed in Japan because of.[1]

## 2 BENEFITS OF THE 3D-CBS TECHNOLOGY

The barrier in PET efficiency improvements during the past 25 years of 2 to 3 fold every 5 years (See reference [20]) can now be broken[4]. The 3D-Flow architecture approach ([1, [2], [3], [21]) used in the electronics of the 3D-CBS breaks the historic pattern of the PET incremental improvements efficiency over time by providing a 400-fold increase in one giant step and opens new doors in the way scanners can operate. (The 400-fold increase in efficiency approaches as close as possible to the theoretical limit. See Figure 4 and Figure 13).

The 3D-Flow architecture simplifies the construction of the electronics and permits (a) the extension of the axial field of view (FOV, which is the length of the detector) to over one meter in length and (b) the capturing, in a cost-effective manner, of about 1,000 out of 10,000 photons in time coincidence, compared to only 2 out of 10,000 photons captured by the best current PET (see Section 4 for the description of the technology, and Section 7.4 for the calculation of over 400 times efficiency improvement).

The unique 3D-Flow architecture of the electronics and other technological improvements allow, for the first time, for the construction of a cost-effective PET scanner with an axial FOV greater than one meter in length. Additionally, these innovations allow a series of breakthroughs in both medical technology and in the way in which medicine is practiced by:

(1) providing for a faster scan (2-4 minutes vs. 50-90 minutes), which can increase the number of patients per hour and lower the examination cost (see Figure 2);

(2) providing better imaging, which permits the detection of cancer and other systemic diseases at earlier stages;

(3) allowing a reduction of the amount of radiation[19] required for a thorough image (25-45 mrem, or about one month's worth of the background radiation one would receive from living in Dallas, instead of 1,100-1,600 mrem, or 4-6 years' worth[19] [22]).

Its faster scanning time[2] allows for examination of over six times the number of patients per day than with current PET (see Figure 2) and yields a five-fold increase in net revenues. The difference is attributable to a marginal increase in operating costs required to scan a larger number of patients and the amortization of a larger capital investment. Table XIII.

During the 3D-CBS examination, the CT scan is free and is made during PET attenuation correction measurements. The higher cost of the larger 3D-CBS detector compared to the current PET (about 2 to 3 times) can be recovered twice as fast because of the significant reduction in radioisotope and personnel costs (six times the number of patients examined per day with 1/30 the radiation dose[19] [22]). See Table XII.

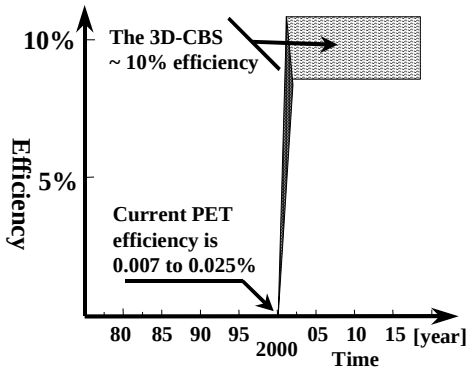



**Figure 4. The innovations of the 3D-CBS break the barrier of 2- to 3-fold improvement in efficiency of PET every 5 years to 400-fold improvement in one breakthrough step.**

Because it provides a broader search for disease over the entire body in only 3 to 4 minutes of 3D-CBS scanning time, several procedures of Table XI could be replaced with one examination at a price floor of the 3D-CBS at $300 as calculated in Table XII. Thus the introduction of a 3D-CBS into the market is desirable from many different aspects, including that of cost reduction. The limitation in efficiency of the current PET is due to its electronics, which are not capable of handling high data input rates from thousands of sources[20]. These electronics were the main impediment to extending the axial FOV which would give a benefit in performance much greater than the additional cost of a longer detector.

## 3 HOW DO IMAGING SCANNERS AND THE 3D-CBS WORK?

The Computed Tomograph (CT) measures the density of body tissue by sending low-energy x-rays (60 to 120 keV) through the patient's body and computing their attenuation on the other side (see left side of Figure 5).

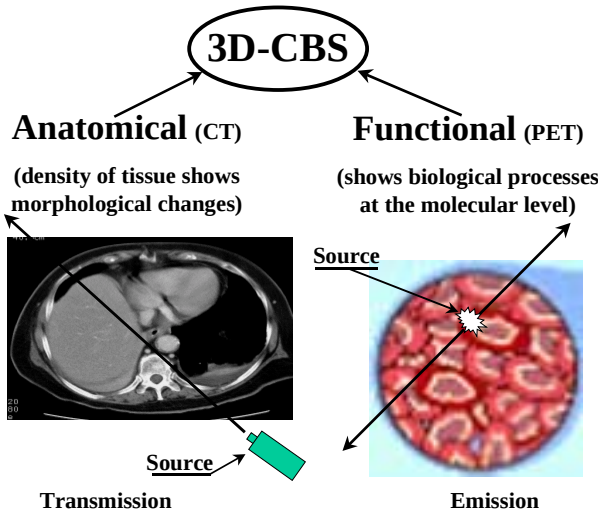


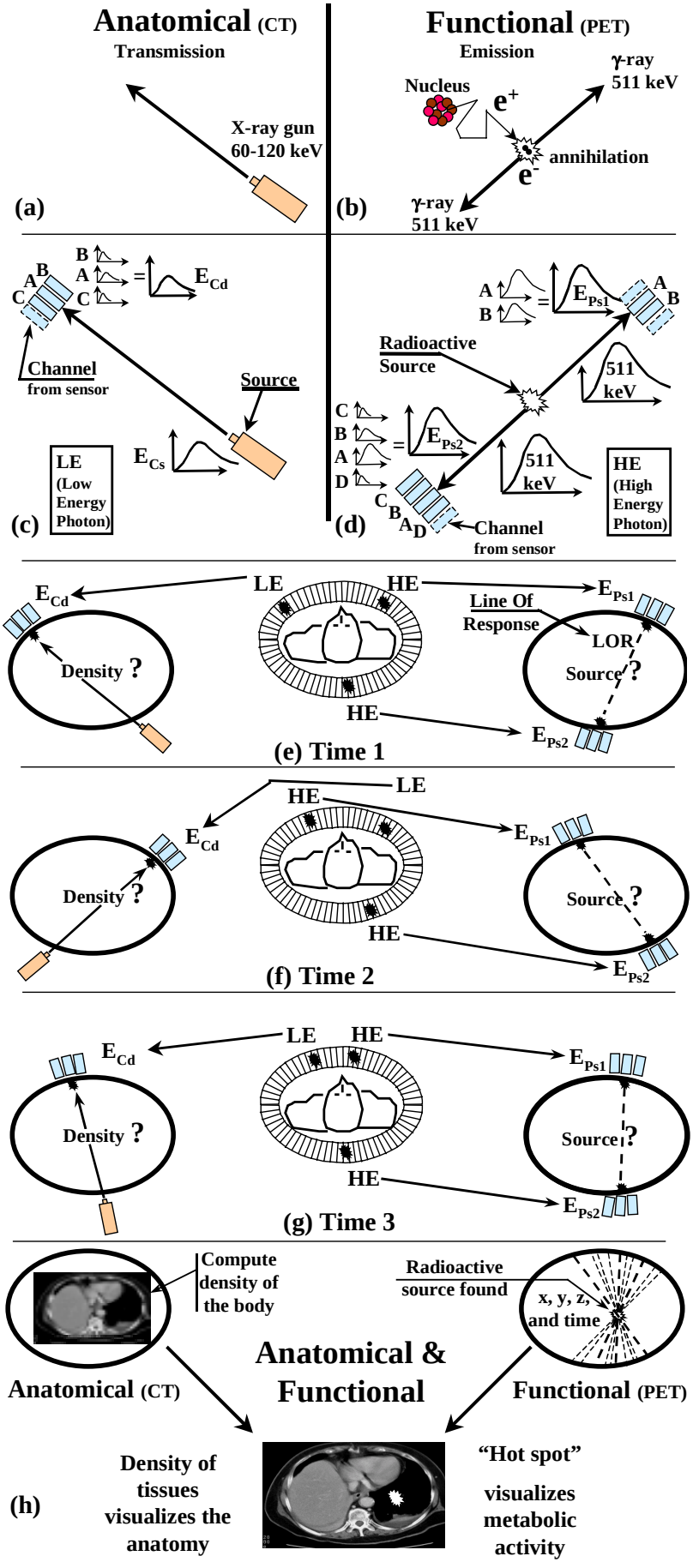

**Figure 5. Differences between CT (left in the figure) and PET technologies (right in the figure).**

[19] The recommended limits of radiation exposure (whole-body dose) are stricter in Europe (maximum 1,500 mrem per year) than in the U.S. (5,000 mrem per year) [22]. However, it is recommended that everyone monitor his/her radiation exposure to keep it to the minimum level.

[20] If the length of the FOV of a PET scanner is extended, the machine could capture more data of the photons emitted from inside the patient's body (see Figure 12).

Positron Emission Tomography (PET) uses radioactive substances injected into the patient's body that emit photons at higher energy (511 keV) and shows biological processes by tracking, at the molecular level, the path of the radioactive compound (see right side of Figure 5). A PET examination detects cancer by using the body's consumption habits (metabolism) and it can monitor blood flow and brain activity.

**Figure 6. Details of the paths of the x-ray (CT) and γ-ray (PET) photons and the technique used to compute the anatomical and functional images. Photons arrive at the detector randomly at unregulated time intervals. When a short time interval of 2 to 3 ns is considered (e.g., as shown in section e, f, and g of the figure) there is a high probability of capturing not more than two high energy photons (HE) in time coincidence from the same PET event and eventually one low energy photon (LE) in the location where the x-ray gun is shooting. The task of the detector and of the electronics is to recognize most of these PET and/or CT events and provide accurate information to the workstation which computes the anatomical and functional images. Each photon is recognized only if thorough measurements are performed on the signals as they are received from the sensors (the photomultipliers –PMT- or Avalance PhotoDiode –APD-) through the electronic channels. Among the most important measurements performed (see additional measurements in next section) are that of rebuilding the total energy of the incident photon. Because a photon may strike the detector crystal in a location where it can produce signals in neighboring sensors, the sum of signals from neighboring sensors must be computed. For example (see section c in the figure) the energy of a CT event measured at the detector $E_{Cd}$ = A + B + C which should be equal to the source energy of the x-ray gun $E_{Cs}$ minus the attenuation caused by going through the body tissue. An example showing the process in PET, found in section d of the figure, shows the energy of one 511-keV photon that has been attenuated by its passage through the patient's body and has been measured as $E_{ps1}$ = A + B; note that the matching 511-keV photon has been measured as $E_{ps2}$ = A + B + C + D. When the detecor receives hits within 2 to 3 ns (e.g., during Time 1 in section e of the figure), the elctronics separates the HE events from the LE event. It finds the location of the HE events and the LOR passing through the two detectors that received the hits. The intersection of millions of LOR per second allow identification of the location of the emitting source as shown in the right side of section h of the figure, while the computation of the attenuation of the x-rays (LE) determines the density of the body and displays its anatomical image on the monitor.**



The patient receives a radioactive isotope (e.g., fluorine $^{18}$F) attached to a tracer (i.e., Fluorodeoxyglucose -FDG - or $^{15}$O-water) that is a normal compound used in the biological process of the human body. It is possible to reveal molecular pathways of the tracer because the radioactive fluorine isotope emits a positron that annihilates with an electron (after a path of about 1.4 to over 13 mm depending on the radioisotope used. See Figure 6b on previous page and Table 7-1 at page 26 of [1]) to produce two photons emitted in diametrically opposed directions. This phenomenon, the annihilation of a positron and an electron simultaneously producing two photons is called "an event."

The two photons travel through and out of the body and are absorbed by the crystals in the detector rings of the PET machine (see Figure 1 and central column of Figure 6e, f, g). The crystals are coupled with photomultipliers (sensors converting light into electrical signals. See shaded rectangles indicated with the letters A, B, C, D in Figure 6d), which in turn send the electrical signals (see top of Figure 7 and Figure 8) to an array of 3D-Flow processors [21], [23], [24], [25], [26]. The processor array analyzes and correlates the received signals with the nearest neighbors, measuring the amount of energy absorbed by the crystals and the arrival time and location of the photon. This information regarding the total energy of each incident photon and their arrival time will be used during phase II of the processing (described later) when the correlation between two far apart photons will be made. This will make it possible to identify the matching pair of photons.

The photons are emitted by the radioisotope inside the patient's body at a rate up to hundreds of millions per second. When the 511-keV γ-ray pair is simultaneously recorded by opposing detectors, an annihilation event is known to have taken place on a line connecting the two detectors. This line is called the "Line of Response" (LOR). (See right column of Figure 6e).

First, with a calculation[4], during phase I, based upon when and where the photons' energies were absorbed by the crystal detector, the electronics identifies the "good photons[21] [27]." (See right column of Figure 6d). Second, each photon needs to find its companion emitted at the same time (or in time coincidence). Third, the pairs of photons are identified and the intersection of millions of LOR per second, indicate the location of the source (x, y, z, and time) and its activity (see right column of Figure 6h) is translated into graphics on a computer screen.

There are areas, such as brain, kidney, and bladder wall, with normally higher metabolism activity than other areas of the body. The computer can subtract from each area the quantity of photons attributed to a normal activity and show only the abnormal metabolism by assigning different colors to level of activity (e.g. yellow for low abnormal activity and red for high). This is a standard techniques in image processing. The physician then looks for abnormal metabolism "hot spots," in the body. The recorded timing information of the data (or their recorded sequential order) will allow the physician to display dynamically, for example, 4 minutes of recorded data in 10 seconds, or to expand one second of recorded data to one minute of dynamic display (e.g., slow motion to better appreciate the speed of the metabolism, or activity, of cancer).

The same electronics of the 3D-CBS also detects photons at low energy (LE) occurring concurrently with the high-energy (HE) photons but being received at the expected locations, according to where the x-ray gun is directed (see Figure 6a, c). The electronics then calculates the attenuation of the signal, which is proportional to the type of body tissue it went through, and computes the anatomical image of the patent's body from this data (see left columns of Figure 6e, f, g, h).

The main characteristic, difference, and value of the PET technology compared to other technologies is the uniqueness of the back-to-back emission of the two 511 keV photons, together with the high sensitivity of the 3D-CBS to uniformly detect the emission source, regardless of its location, offers a unique 3-D imaging capability.

The biochemical processes (e.g., metabolizing glucose) of the body's tissues are altered in virtually all diseases, and metabolism is indicated in PET by higher than normal photon emission.

Cancer cells, for instance, typically have a much higher metabolic rate, because they are growing faster than normal cells and thus absorb more sugar (60 to 70 times more) than normal cells and emit more photons [4], [7]. Inflammatory diseases also absorb more sugar than normal cells.

Detecting these changes in metabolic rates with the PET enables physicians to find diseases at their very early stages, because in many diseases, the metabolism of the cells changes before the cells are physically altered. Similarly, a PET machine can use different radioactive substances to monitor brain or heart metabolism activity.

In general, PET technology has already replaced multiple medical testing procedures with a single examination. In many cases, it diagnoses diseases before they can be identified by their morphological changes in other tests or with other devices.

Combining different technologies in one device further assists physicians in clinical examinations. Viewing PET functional imaging data in conjunction with CT morphologic cross-sectional data is sometimes mandatory if lesions are found.

[21] Good photons are those that originate from the same event and that arrived at the detector straight from the source without bouncing off in other matter (Compton scatter). Efficient electronics at the front end can identify some Compton scatter events by accurately measuring the energy and the time of arrival of the photons, however, other Compton scatter events can only be identified after acquisition during the image reconstruction phase [27]. Missing good photons fails to provide a clear image to help the physician recognize subtle differences in normal anatomies.

# 4 WHAT ARE THE KEY INNOVATIONS IN THE 3D-CBS ENABLING IT TO CAPTURE MORE PHOTONS?

The most significant improvements the 3D-CBS offers over the PET are: (a) capturing more data from the emitting source and (b) processing the acquired data with a real-time algorithm which best extracts[4] the information from the interaction between the photons and the crystal detector.

If more data from a radioactive source used currently (or from a source with lower radiation activity) is captured by the detector, sent to the PET electronics, and processed correctly, then the examination time, radiation dosage, and consequently also the cost per examination can be significantly reduced.

In order to obtain more data, the axial field of view (FOV, the total length of the rings of crystals in the scanning detector) must be lengthened to cover most of the body. In order to process these data, the electronics must be designed to handle a high data input rate from multiple detector channels. The 3D-CBS can handle up to 35 billion events per second with zero dead time in the electronics (when a system with 1,792 channels as described in [2] is used), versus the 10 million events per second with dead time that the current PET can handle [28], [29], [30], [31]. High input bandwidth of the system is necessary because the photons arrive randomly, at unregulated time intervals. (See Section 13 and 14 of [1]).

The references [2], [21] describe (a) a novel architectural arrangement of connecting processors on a chip, on a Printed Circuit Board (PCB) and on a system, and (b) a new method of thoroughly processing data arriving at a high rate from a PET detector using the 3D-Flow sequentially-implemented parallel architecture [1], [3] (See Table III and Figure 9).

In layman's terms, the processing of the electronics on the data arriving from the detector can be compared to a task of the reunion of families that were separated by a catastrophic natural event. The following analogy in human terms is made; the sequence of the events in the family reunion example is one billion times slower than the sequence of events in the PET:

- A catastrophic event separates on average 20 families every 50 seconds. During the attempt to reunite the families, unfortunately, only about 12% of the husbands and wives can arrive at a reunion center.
- When a family was split, the husband and wife went in opposite directions, each with some of their children (similar to the back-to-back photons of the PET as described in Section 3 and shown in Figure 6b). In the analogy, the children in neighboring channels and the father (or mother) represent signals on neighboring sensors (or electronic channels) which have been generated by a photon striking the detector. The analogy lies in the fact that the total energy of the incident photon that was split among several neighboring channels (or wires; see Figure 7 for an example showing channels A, B, C, and D of Figure 6c and d, the top of Figure 7 and the top of Figure 8) must be rebuilt, just as the parent must be reunited with his children.

The family reunion takes place in two phases. During the first phase, the father and the children who went with him but followed a neighboring path (channel or wire) are reunited. The same process is followed independently, in a separate venue, by the mother with their other children, however, that will take place far apart from where the father is. During the second phase the two half-families are reunited.

Figure 7 shows an example of information split over several channels (or wires). A photon striking in such a way that its information is divided among several electronic channels is analogous to one parent with some children going down several channels (see on the second row the split of a family among four wires, and on the third row the split of a family between two wires).

Because there are on average about 5 groups of fathers with children (or mothers with children) arriving randomly, at unregulated time intervals every 50 seconds at any place in the approximately 2,000 channels at the reunion center, it is necessary to reunite the half-family (rebuild the energy of the incident photon) at their arrival site, before the children are mixed with millions of other people.

**Phase I: Reunite the half-family (rebuild the energy of each incident photon, determine its exact arrival time, measure the exact position of its center of gravity, measure the DOI, and resolve pile-up).**

The solution to the problem of phase I, which is illustrated in a cartoon of the "family reunion" of Figure 8, is mainly provided by the "bypass switch" (or multiplexer) of the 3D-Flow architecture (see Table III and Figure 9). Information concerning the father and children, that is, the signals generated by the photon, arrives at the top of the channel (wire) and moves down one step each time new data arrive at the input. The numbers in Figure 8 correspond to the position of the objects at time 14t of Table III. Objects outlined in dotted lines correspond to the status one instant before time "14t."

The 3D-Flow architecture allows a high throughput at the input because (a) each data packet relative to the information about the photon (or about the family member) has to move at each step only a short distance, from one station to the next, and (b) complex operations of identification and measurement can be performed at each station for a time longer than the time interval between two consecutive input data.

Every time a new data packet arrives at the top of the channel (or wire), all other data packets along the vertical wire move down one step, but the wire is broken in one position where the station is free to accept a new input data packet and is ready to provide at the same time the results of the calculations of the previous data packet.

In other words, at any time, four switches in "bypass mode" and one switch in "input/output mode" (or the wire broken at a different place) are always set on the vertical wire. This synchronous mechanism will prevent losing any data at input and will fully process all of them.

When a data packet relative to a photon enters a measuring station (that is, a 3D-Flow processor, or the station represented on the right side of Figure 8), it remains in that station for its

complete identification, measurements, and correlation with its neighbors. Several operations are performed at each station:

1. A "picture" is taken and sent along with the time of arrival to the neighbors, while "pictures" from the neighbors, along with their time of arrival are also received and checks are performed to see if there were any family members in the neighboring channels (similarly the energy and arrival time of photons are exchanged between neighboring elements to check if the energy of the incident photon was fragmented between several channels).
2. Local maxima (checking to see if the signal is greater than the neighbors) are calculated to determine if the parent arrived at that channel; this is equivalent to comparing the photon's energy and arrival time to similar information in the neighboring channels. If the parent did not arrive at that channel, the process at that channel is aborted to avoid duplication. The neighboring channel that finds the father will carry on the process.
3. Center of gravity is calculated (that is the point at which the weight of an object is equally distributed). This calculation will provide an accurate location where the half-family was found; this is equivalent to the spatial resolution of the incident photon.
4. Pile-ups are resolved, which occur when two half-families belonging to two different families arrive within a very short time interval, or when two events occur in a nearby detector area within a time interval shorter than the decay time of the crystal. When this happens, the apparent integral of the second signal will show it riding on the tail of the previous signal. Digital Signal Processing (DSP) techniques of the 3D-Flow processor can detect the change of slope of the tail of the signal and separate the two signals.
5. The accurate arrival time of the half-family group is calculated and assigned to be carried for the rest of the trip; similarly, the accurate arrival time of the photon is calculated.
6. Other measurements are performed on the input data (half-family or photon), such as the depth-of-interaction (DOI) on the incident photon. DOI measurements solve the problem of identifying the affected crystal when the incident photon arrives at an oblique angle instead of perpendicularly to the face of the crystal. Several techniques [32], [1], [33], [34] of DOI measurements which allow for correcting the effect commonly referred as "parallax error" can be performed by the 3D-Flow processor.
7. Finally, the half-family is reunited (total energy of the photon is calculated), all measurements are performed and results are sent back to the channel for its trip to the exit (See in Figure 8 the object r4 in the fourth station from the top, which is the result of the input data No. 4).

Only some of the above processing is carried on in the current PET. The most important task of rebuilding the energy of the incident photon (equivalent to reuniting a half-family) is not performed. On the contrary, current PET adds analog signals before checking whether the signals belong to the same incident photon (equivalent of checking to see if a member belongs to the same half-family).

This operation in current PET turns out to be very counterproductive at the next electronic stage because the analog signal (which is the sum of several signals) cannot be divided into its original components and the information on the single photons that is needed for several subsequent calculations is instead lost forever.

In the most advanced current PET, the electronics cannot complete the processing before the arrival of another data, and consequently dead-time is introduced and photons are lost.

The conclusion is that the limitation of the electronics of the current PET (front-end and coincidence detection described later) does not detect many photons and the overall performance of the best current PET detects about 2 photons in time coincidence out of 10,000 emitted by the radioactive source. This should be compared to 1,000 photons out of 10,000 captured by the 3D-CBS, with its improved electronics and extended axial FOV. In addition, of the 2 out of 10,000 photons in coincidence captured by current PET, many will be discarded by subsequent processing, or will not carry accurate information. For example, the measurements of the center of gravity (which affect spatial resolution) cannot be accurate in current PET because the full energy of the incident photon was not rebuilt. Photons whose energy was split between two channels are lost.


**Figure 7. "Family reunion." A solution, that identifies family members and checks in detail for their characteristics, is needed for the reunion of related pairs of photons. The figure shows an example of the arrival of information of the particles from several electronic channels at one time. In the figure, several members of a family arriving at the same time on different electronic channels (e.g. see four members of a family in the second row from top) are compared to a photon that has its energy split among several channels.**

**TABLE III. SEQUENCE OF THE DATA PACKET AT DIFFERENT TIMES IN THE PIPELINE STAGE (SEE FIGURE 9). ONE DATA PACKET IN THIS APPLICATION CONTAINS 64-BIT INFORMATION FROM ONE CHANNEL OF THE PET DETECTOR. THE CLOCK TIME AT EACH ROW IN THE FIRST COLUMN OF THE TABLE IS EQUAL TO $t = (t_1 + t_2 + t_3)$ OF FIGURE 9. THE NUMBER IN THE LOWER POSITION IN A CELL OF THE TABLE IS THE NUMBER OF THE INPUT DATA PACKET THAT IS PROCESSED BY THE 3D-FLOW PROCESSOR AT A GIVEN STAGE. THE VALUES IN THE RAISED POSITION, INDICATED AS ix AND rx, ARE THE INPUT DATA AND THE RESULT DATA, RESPECTIVELY, WHICH FLOW FROM REGISTER TO REGISTER IN THE PIPELINE TO THE EXIT POINT OF THE SYSTEM. NOTE THAT INPUT DATA 1 REMAINS IN THE PROCESSOR AT STAGE 1d FOR FIVE CYCLES, WHILE THE NEXT FOUR DATA PACKETS ARRIVING (i2, i3, i4, AND i5) ARE PASSED ALONG (BYPASS SWITCH) TO THE NEXT STAGE. NOTE THAT AT CLOCK 14t, WHILE STAGE 4d IS FETCHING 9, IT IS AT THE SAME TIME, OUTPUTTING r4. THIS r4 VALUE IS THEN TRANSFERRED TO THE EXIT OF THE 3D-FLOW SYSTEM WITHOUT BEING PROCESSED BY ANY OTHER d STAGES. NOTE THAT CLOCK 14t IS SHOWS THE STATUS REPRESENTED IN FIGURE 9 AND THAT INPUT DATA AND OUTPUT RESULTS ARE INTERCALATED IN THE REGISTERS OF THE 3D-FLOW PIPELINED SYSTEM.**

| Time | Proc (1d) | Reg (1d) | Proc (2d) | Reg (2d) | Proc (3d) | Reg (3d) | Proc (4d) | Reg (4d) | Proc (5d) | Reg (5d) |
|---|---|---|---|---|---|---|---|---|---|---|
| | data # | data # | data # | data # | data # | data # | data # | data # | data # | data # |
| 3t | 1 | | | | | | | | | |
| 4t | 1 | i2 | | | | | | | | |
| 5t | 1 | i3 | 2 | | | | | | | |
| 6t | 1 | i4 | 2 | i3 | | | | | | |
| 7t | 1 | i5 | 2 | i4 | 3 | | | | | |
| 8t | 6 | r1 | 2 | i5 | 3 | i4 | | | | |
| 9t | 6 | i7 | 2 | r1 | 3 | i5 | 4 | | | |
| 10t | 6 | i8 | 7 | r2 | 3 | r1 | 4 | i5 | | |
| 11t | 6 | i9 | 7 | i8 | 3 | r2 | 4 | r1 | 5 | |
| 12t | 6 | i10 | 7 | i9 | 8 | r3 | 4 | r2 | 5 | r1 |
| 13t | 11 | r6 | 7 | i10 | 8 | i9 | 4 | r3 | 5 | r2 |
| 14t | 11 | i12 | 7 | r6 | 8 | i10 | 9 | r4 | 5 | r3 |

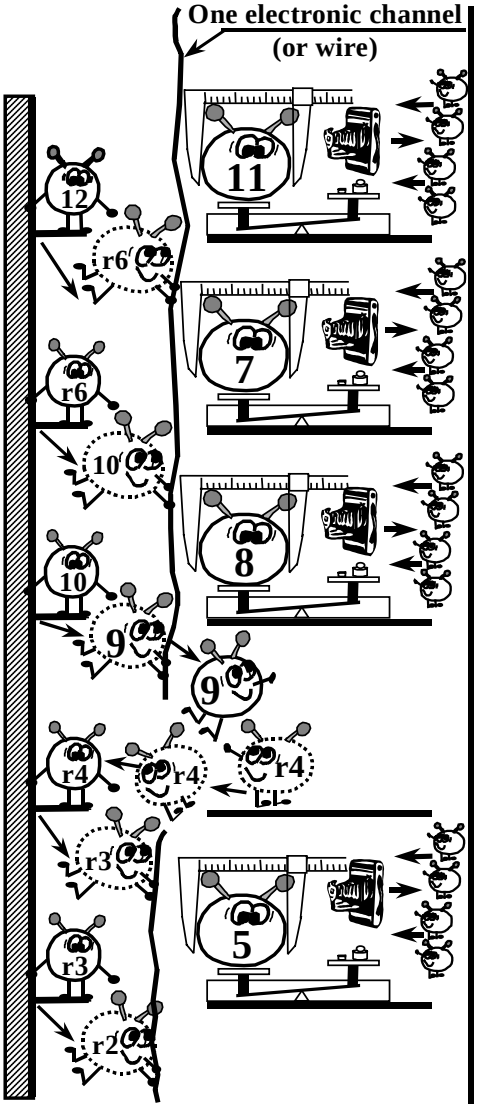



**Figure 8. A "family reunion" cartoon for time 14t of Table III and Figure 9. Each photon remains in the measuring station (processor) for a duration five times longer than the time interval between two consecutive input data. The result from any measuring station will not be an input to the next station (as it is in a typical pipeline system) but will be passed on with no further processing in the 3D-Flow sequentially implemented, parallel-architecture until it exits (see additional description on next page).**

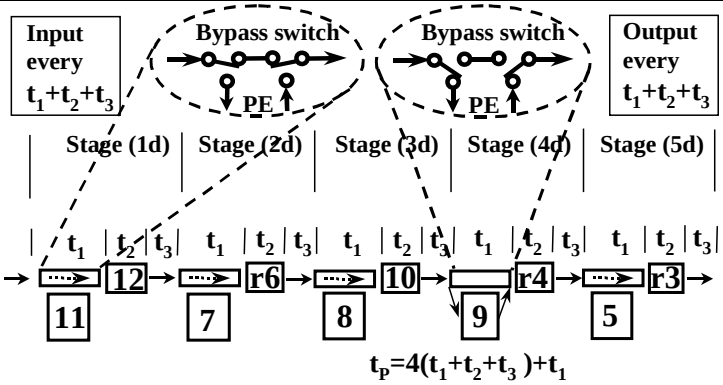



**Figure 9. The example shows how the 3D-Flow system extends the execution time in a pipeline stage beyond the time interval between two consecutive input data (sequentially-implemented, parallel architecture). An identical circuit (a 3D-Flow processor) is copied 5 times at stage d (the number of times the circuit is copied corresponds to the ratio between the algorithm execution time and the time interval between two consecutive input data). A bypass switch (shown as a dotted right arrow in the figure) coupled to each processor in each 3D-Flow stage 1d, 2d, 3d, 4d, and 5d sends one data packet to its processor and passes four data packets along to the next stage ("bypass switch"). Thus, the execution time at each substation d will be $t_P = 4(t_1 + t_2 + t_3) + t_1$. The numbers in the rectangles below the switches identify the input data packets to the CPU of the 3D-Flow processor. (See also Table III for the sequence of operations during the previous clock cycles). A 3D-Flow processor is shown in the figure with the three functions of (a) a bypass switch (dotted right arrow in the rectangle), (b) an output register (rectangle to the right), and (c) a CPU (rectangle below).**

Conversely, the advantage of the 3D-Flow architecture of the 3D-CBS is a result of the use of several layers of stations (processors) with the data flow controlled by the "bypass switches," allowing more than 50 seconds (50 ns for the photons) to weigh the subject, to take the picture, to exchange them with the neighbors, to calculate the local maxima, the center of gravity, etc. Five layers of stations (or processors at the same level) allow 250 seconds in each processor to perform all the above calculations. In the event this time is not sufficient more layers are added. The bypass switches at each station will provide good synchronization of input data and output results at each station by simply taking one data package for its station and passing four of them along.

Using the scheme of Figure 8 we can follow the path of a data packet of photon (i3) through the entire system. At time 5t shown in Table III, the data packet of photon i3 enters the channel at the top of Figure 8. If it finds a busy station (processor) on the right, it rests for one cycle on the platform (or register, shown in Figure 9 as a rectangle next the bypass switch).

During the next cycle (6t of Table III), this data packet of photon (i3) advances to the next station. If this station is also busy, then it will rest on the next platform, and so on until it finds a free station.

When the data packet of photon (i3) finds a free station (at time 7t in Table III), it enters the station and stays there for five cycles for measurements (processing). After the data packet of photon (r3, which contains the results of the processing performed on i3) leaves the station and goes to the platform on the left, adjacent to the station (at time 12t), another data packet of photon (i8) enters the station from the upper left platform. The result from photon (r3) cannot go straight to the exit but can only advance one platform at a time until it reaches the exit.

**Phase II: Reunite husbands and wives (the two half-families reunited in phase I) from locations far apart (or find the back-to-back photons in time coincidence).**

The measurements performed during phase I have reunited the half-families (each parent with some children), creating good candidates for the final entire family reunion. The result of the previous process is that, at most, four new fathers (or mothers) are found every 50 seconds.

The approach used in current PET in the final reunion is that the fathers and mothers do not move from the location where they are and each location interrogates about half of all the other locations[22] [29], [31] in order to find out whether there is a companion in that location.

Because, as we have mentioned, there are about 2,000 locations (electronic channels) in the system, the total number of comparisons required to be performed in order to find the companion will be enormous. For instance, for a PET with 1,792 channels, the number of comparisons necessary would be: (1,792 * 1,791)/4 = 802,368 comparisons every 50 ns; that is equivalent to $1.6 \times 10^{13}$ comparisons/second. Although in our human analogy family events are one billion times slower, it would still require $1.6 \times 10^{4}$ checks of matching families per second.

In order to avoid making that many comparisons per second, manufacturers of current PET have reduced the number of locations (electronic channels). This has several drawbacks such as increasing dead-time, reducing resolution, etc. For example, with a reduction to 56 channels, the number of comparisons in current PETs is still (56 * 55)/4 = 770 comparisons every 250 ns, equivalent to about 3 billion comparisons/second, which are performed in seven ASICs in the current GE PET [31].

The approach used in the proposed 3D-CBS (described in Section 13.4.14 and shown in detail in Figure 13-22 of [1]) is simple. It greatly simplifies the circuit and requires only 120 million comparisons per second for an efficiency equivalent to that of the PET with 1,792 channels, which, as noted above, would require instead $1.6 \times 10^{13}$ comparisons per second.

In layman's terms, the approach can be explained as follows: the husbands and wives should move from their location to the reunion center. At that location an average of 4 groups of parents with children arrive every 50 seconds, thus in order to make all possible combinations among 4 elements and avoid accumulation in the room, 6 comparisons every 50 seconds are necessary. This would still be manageable in the world of the family reunion, only 6 comparisons being required instead of $1.6 \times 10^{4}$ comparisons per second with the current PET approach) and it would also be manageable in the world of photons requiring only 6 comparisons every 50 nanoseconds, which is equivalent to 120 million comparisons per second.

# 5 HOW IS THE TECHNOLOGY VERIFIED?

The novel 3D-Flow architecture can be verified from the conceptual level (as described in several documents [26], [21], [23], [2]), down to the silicon gate level.

First, the verification that the unique architecture can be implemented with processors running at a normal speed of the order of 100 MHz (to avoid prohibitive costly silicon technologies, e.g., GaAs) is done logically.

The verification of the advantage at the conceptual level can be performed by anyone by comparing the old approach with bottleneck described in [28] [35], [31], and the new 3D-Flow approach eliminating bottlenecks, as described in the previous section, in Section V of [2] (see also Section 13 and 14 of [1]).

Second, the verification at the behavioral is performed in C++ by the 3D-Flow design real-time tools [21], [26], where the model of each electronic component has been defined at the register level. The user can advance step by step in the simulation and verify that each predefined section of the electronics processes the data correctly and that the expected results are generated.

Third, the verification at the silicon gate level has already been accomplished with the synthesis of the 3D-Flow chip with four processors per chip in CMOS 0.35 micron technology,

[22] see the details on [29], [31] explaining that it is not necessary to test Line of Response – LOR - which do not pass through the patient's body

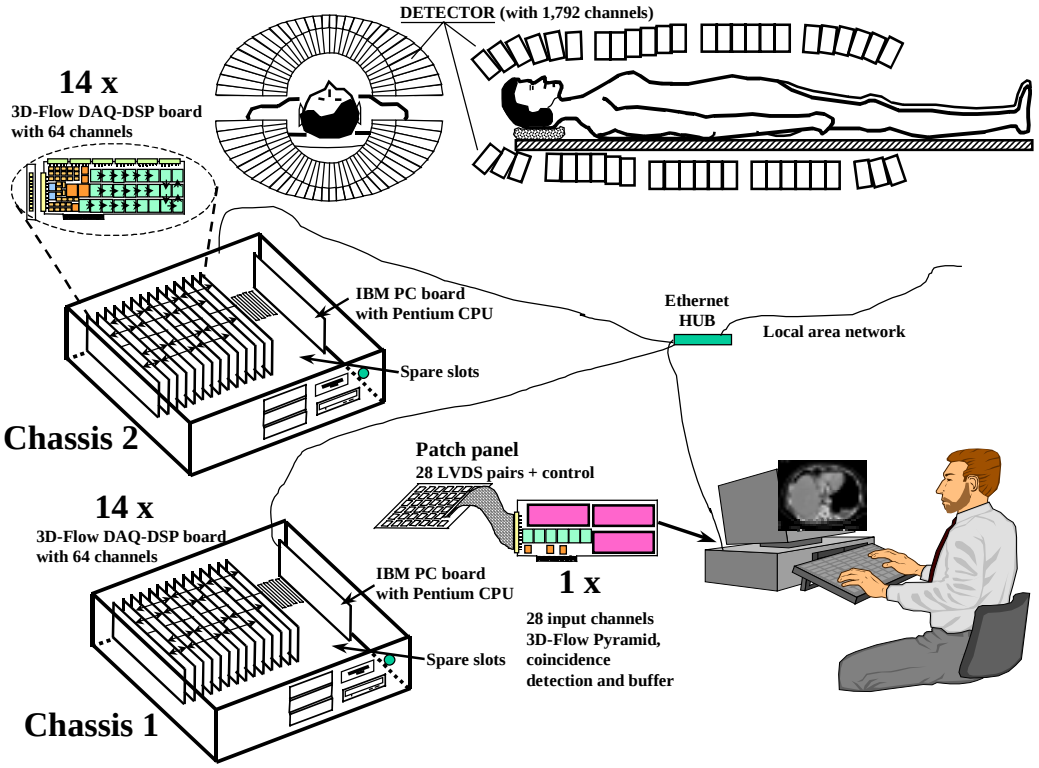



**Figure 10. Layout for the hardware assembly of the 3D-CBS.**

(and for FPGA technology with one processor per chip). See Section C and D of [26].

The 3D-Flow chip design is in a technology independent, IP (Intellectual Property) form suitable to be implemented in the latest and most cost-effective technology. Tools and procedures are available [21], [26] for:

- Verification by comparison
  - Timing produces compatible results (e.g., same steps for a division, multiplication, 32 comparisons)
  - Functions (or instruction) produce the same results (e.g., fixed-point multiply produce same result, resolution)
  - Entire real-time algorithms produce the same result (e.g., by comparing results of application programs)
- Verification on behavioral and gate-level netlist
  - Gate-level netlist verified pre- and post-route.

The verification at the system level for a PET with a 3D-Flow system providing an input bandwidth of 35 billion events per second distributed over 1,792 input channels (well beyond the inefficient electronics of current PET) is described in [2].

The entire system (see Figure 10) can be verified and monitored by a separate workstation (System Monitor) connected to the Virtual Processing system (or real hardware) through Ethernet (which is further connected to each 3D-Flow chip of the system implemented on 28 IBM PC boards through RS232 interfaces. See references [21], [26]).

The construction of the overall machine integrating PET and CT capabilities is not very difficult because components have already been built, tested, and verified by measurements and these results have been made available to several parties.

## 6 COST OF THE 3D-CBS DEVICE

Although the cost floor price of an examination using the 3D-CBS can be as low as $300/exam, (compared to the current $2,000 to $4,000 for a PET exam) due to higher scanning speed, lower cost of the radioisotope and personnel, the cost of the machine, about $6 million, is two to three times the cost of the current PET.

The estimated cost of $6 million for the 3D-CBS has been derived from the cost of the main components of the current PET in the following manner

For comparison, the largest PET commercially available PET has been considered: The volume of the crystals of a CTI/Siemens 966/EXACT3D is about 13,602 $cm^3$. Assuming the cost of BGO crystal detectors to be $10/$cm^3$, the cost of the crystals is $136,020. Assuming the cost of 3/4" PMT to be $160 each, 1,792 PMTs cost $276,480. By estimating the cost of the electronics to be $100,000, the total cost of the main materials of a 966/EXACT3D is about $512,500. When all other components such as assembly, software, marketing, etc, are included, the price must be multiplied by five times to arrive at about $2.5 million for the retail price.

Similarly, the cost of the main components of a 3D-CBS, assuming the cost of the crystals being about $10/$cm^3$, is: about $500,000 for the crystals (calculated for a 25-mm thick, small ring for the head, and elliptical form for the torso); about $350,000 for the phototubes (assuming the cost of the 1 1/2"

PMT, with the same functionality of four old ¾" PMT, to be $200 each, 1,792 PMTs will cost about $350,000); and the electronics is estimated to cost about $200,000 (calculated as 28 x 3D-Flow DAQ-DSP boards with 64 channels each, costing $5,000 each, plus $60,000 for two IBM PC CPU, two IBM PC chassis, one 3D-Flow pyramidal board, hard drives, ancillary logic, and cables. See Figure 10 of this article, Section XIII of [2] and Section 17.2 on page 181 of [1] for details), for a total of about $1 million. An equivalent pricing of the main components applied to the current PET available on the market requires one to multiply this number by five to include assembly and other parts in order to obtain the estimated retail price of $5 million.

The additional cost of the CT section (which is a proven technology and can be built using a traditional moving x-ray gun head, or a more advanced electron beam technique such as the one shown in Figure 3 of [2]) includes only the cost of the x-ray generator. The other components such as the detectors, photomultipliers and the electronics are the same as the ones used for PET. For the additional components for the CT scanner, the cost has been generously estimated $1 million. The CT + PET will make a 3D-CBS device with a cost of about $6 million.

# 7 TECHNOLOGY HIGHLIGHTS OF THE 3D-CBS WHICH PERMIT ANNUAL CANCER SCREENING

A more detailed analysis of the deficiencies of current PETs, how those limitations are remedied by the 3D-CBS (with precise references to the distinctive innovative features of the 3D-CBS to which the improvements are attributed) can be found in Appendix C.

The 3D-CBS' breakthroughs in four areas allow for improvements of: (a) quality and quantity of detection; (b) speed of detection; (c) lower radiation dosage requirements; and (d) lower costs.

## 7.1 Quality and quantity

In the 3D-CBS system, there is a one-to-one correspondence between a processor cell and a detector channel (or sensor, or electronic channel. See details in [21], [2]). If a photon lands across the borders of detector channels (see Figure 11), the signals sent by each sensor to its corresponding processor need to exchange their information with the neighbors in order to be able to reconstruct the total energy of the photon. This operation increases the sensitivity[23] by capturing more good[21] photons which are essential to reduce the "false positives" and "false negatives." The exchange of signals between neighboring channels with no detector boundary, allow signals interpolation which also improves spatial resolution. (Both affect the image quality).

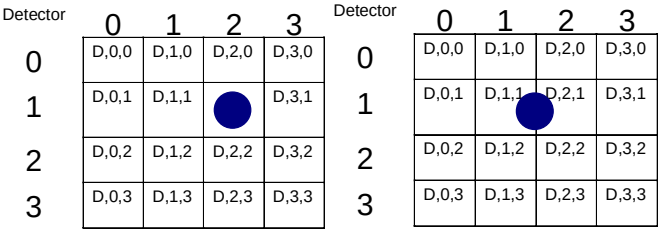



**Figure 11. Inefficiency of current PET to detect photons when they strike the crystal in a location that can produce signals in neighboring sensors. Case (figure at left) when a photon is detected because it strikes a detector which is coupled to a sensor (or a group of sensors such as photomultipliers, or APDs. Most of the current PET have sensors organized in groups of 2 x 2 elements). Case (figure at right) when a photon is undetected in current PET because it strikes a detector that produces signals in neighboring sensors (or group of sensors). The 3D-Flow approach remedies this limitation by exchanging the information with processors receiving signals from neighboring sensors.**

More photons emitted by a single organ can be captured if the FOV is increased. Figure 12a shows that by doubling a short field of view the number of photons that can be captured is actually increased by a factor of four instead of two. Figure 12b shows that also the image resolution is increased by increasing the axial FOV.

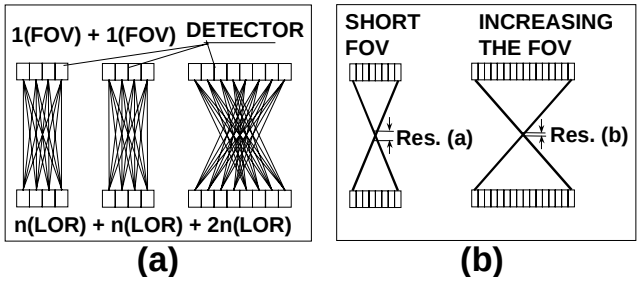



**Figure 12. A PET, with an axial FOV that is twice as long as the FOV of the current PET, can detect four times the number of photons in time coincidence from an organ emitting photons from the center of FOV. Section (a): Doubling the axial FOV increases the Line of Response (LOR), thus the sensitivity increases four times when doubling a short axial FOV, this should enable the user to detect four times the number of coincidences when the electronics do not saturate and DOI measurements are performed. Section (b): Increasing the axial FOV increases the resolution.**

## 7.2 Speed

The fast scanning time of the 3D-CBS is because of the long axial FOV of its detector and the highly efficient electronics. The high photon detection efficiency (of 1,000 out of 10,000 compared to 2 out of 10,000) reduces the time needed for acquisition of the 20 million photons in coincidences (or the amount of photons which provide a

[23] The need to increase the sensitivity that helps to reduce the false positives and false negatives is demanded by the users, while the sensitivity that also increases the noise which provides worst images is undesired. The DSP on each electronic channel[4] allows the improvement of the S/N ratio on signals before adding them. An observation referring to the disadvantages of the increased sensitivity with an equivalent or more increase of noise in the current PET was made by Dr. Alan Waxman [8], director of the nuclear medicine Cedars-Sinai Medical Center in Los Angeles. He stated "The bad news is that the new systems [PET] are so sensitive to minute accumulations of fluorine-18 fluorodeoxyglucose (F-18 FDG) that it has become harder to tell the difference between malignancy and inflammation." Obviously, this type of increase in sensitivity offers no advantages.

sufficient statistic to yield a good image). This allows the examinations to be performed in 15 to 20 minutes with 3 to 4 minutes scanning time, (a) facilitating the capture of a specific biological process one desires to observe, (b) without making the patient uncomfortable, and (c) at a greatly reduced cost. (See Figure 2).

## 7.3 Less radiation to the patient

The loss of efficiency in the current PET is not only due to the shorter axial FOV and the smaller solid angle as shown in Figure 13; a great fraction is cause by the inefficiency of the electronics.

The current PET imaging machines do not thoroughly analyze in real-time the data received from the detector, which contains the information of the characteristics of the interaction between the incident photon and the crystal. The result is that many "good[21]" photons are missed and photons are captured that later in the process must be discharged as "bad" photons. Conversely, the electronics of the 3D-CBS can perform a thorough[4] analysis on the incoming data at high rate.

Figure 13 shows the factors contributing to an increase in radiation dose to the patients when current PETs are used. Although the text cannot be easily read in the figure, the symbols in the picture show clearly the difference between the old approach used in current PET (left in the figure) and the new 3D-CBS approach (right in the figure) and where the great areas of inefficiency are. See more details on Section 14 and Figure 14-1 of [1]).

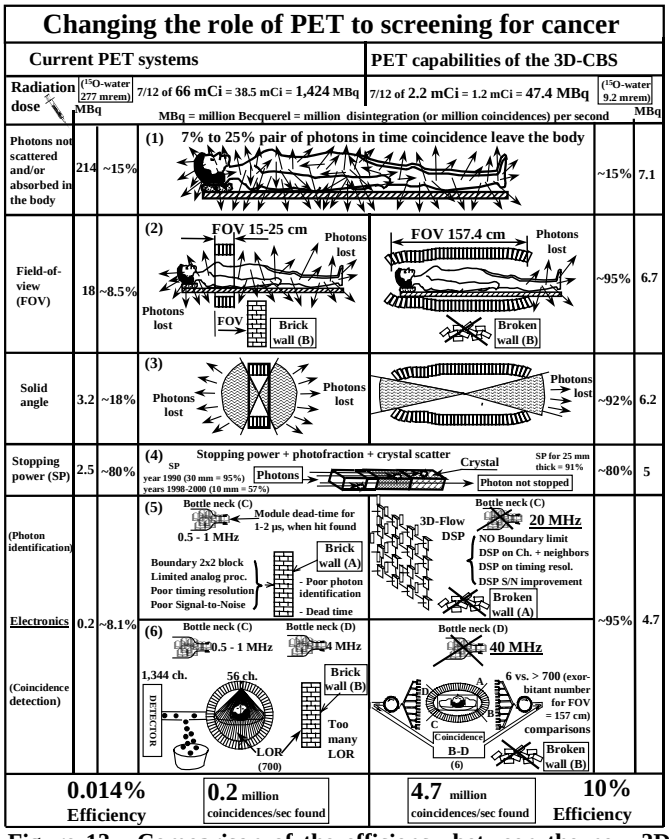



**Figure 13. Comparison of the efficiency between the new 3D-CBS (right side) and the current PET system (left side).**

## 7.4 Measurements of the inefficiency of current PET

The measurements of the limited efficiency of the current PET devices have been reported in articles written by manufacturers. (See references [36], [37] and Sections 11.2.2.6.3.2 and 11.2.2.6.4.2 of [1]). **The calculation of the improved efficiency over 400 times using the new 3D-CBS compared to the current PET is reported in [1] and is calculated as follows**: the division between 10% divided by 0.014% = 714 (see lower part of Figure 13). The 0.014% is calculated as the division of the 0.2 million coincidences/sec detected divided by 1,424 million coincidences/sec emitted by the radioisotope. Both values are taken from Figure 8 on page 1405 of the article by DeGrado et al. [37]. The improved efficiency of 10% in the 3D-CBS is due to its breaking of the barrier of the axial FOV by a novel simplified design of the electronics (which will also improve the performance of current PET with short axial FOV if the electronics are replaced). See Section 14 of [1] for more details.

# 8 BENEFITS OF THE 3D-CBS TO THE CURRENT DIAGNOSTIC WORKUPS

After describing the technology of the 3D-CBS and its advantages it is important to review the benefits and cost saving on its applications. Among the two application areas of the 3D-CBS (early detection and diagnostic workup) mentioned in Section 1.2, for the second area of application, the 3D-CBS can be seen as a modern PET machine for diagnostic workup of symptomatic patients with over 400-fold efficiency improvement. It will improve the current PET and CT area of applications because the unique approach of the architecture of the electronics together with other unique features of the 3D-CBS (on the 3D-Flow [25], [23], [26] have already succeeded in innovating around the most difficult technological hurdles and providing solutions that break the current PET efficiency barriers[4].

Because the 3D-CBS reduces the radiation to which the patient should be exposed, it does not present any new risks and the agencies such as Food Drugs Administration (FDA) in the U.S., which have approved CT and PET examinations at higher radiation dosages, should approve 3D-CBS exams at lower radiation dosages.

## 8.1 Use of the 3D-CBS in current medical imaging devices for diagnostic workups on symptomatic patients.

Table IV and Figure 14 summarize the current U.S. market (historical and projected) of scanners[24] related to the 3D-CBS (notice the growth of 9,000 CT scanners during fifteen years, which reached 11,500 units by the year 2000 and the conservative proposed growth of only 1,000 3D-CBS units over five years).

[24] Historical and projected PET data based upon the studies of Diagnostic Imaging [8] (DI predicts over 500 PET by 2003).

EXPLANATION OF THE RECENT DRAMATIC EXPANSION OF THE MEDICAL IMAGING MARKET FOR DIAGNOSTIC WORKUP ON SYMPTOMATIC PATIENTS AND THE FASTER GROWTH EXPECTED IN THE FUTURE

The 3D-CBS provides the best integration of the PET/CT in a single detector apparatus without the need to move the patient or the detector during a whole-body PET scan. The combined PET/CT exams are predicted to grow in the future by experts[7] in the medical imaging field.

As an example, the U.S. market has been analyzed in detail in this document, however, the entire world-wide market is over three times the size of the market described here, and the benefits of larger diagnostic machines compared to small machines to diagnose diseases in individual organs has been proven to be advantageous by several experts[26] in the world.

Even if one makes conservative pessimistic market assumptions that there will be no growth of the market, the faster and more efficient 3D-CBS will provide better quality exams, at lower cost with a lower radiation dose. The study compares operating costs of the 3D-CBS and the current PET at very high volumes and prices and very low prices and volumes of utilization. Following, several different trends are evaluated and justifications for current medical imaging experts' belief that the PET and CT market is going to grow[24] at a rate even greater than the over 60% annual growth for PETs of the past years:

1. The two major PET producers, GE and Siemens, sold a total number of 100 PET machines in 2000 (at a price of over $2 million per machine) and are scheduled to sell over 150 PET machines in 2001, with a back order/waitlist of over six months. Several sources[24] indicate that the U. S. will have over 500 PETs by 2003.

2. In the United States, the total health care costs [11] exceeded $1.2 trillion in 1999. Approximately 1.1% of this total has consistently been spent on medical imaging.[25] This trend will continue, because additional studies indicate that medical imaging devices save HMOs and the government billions of dollars every year[26] [6], [5]. There will be a preference for the 3D-CBS because it offers a higher quality image than the current most accurate machine (the PET) at an examination price and speed comparable to a CT scan. In additional studies have demonstrated that PET based machines are much more likely to detect cancer[27] than CT devices [38], [39], [40].

3. The PET coverage by the health insurance companies and HMOs is increasing. HCFA, the body responsible for approving Medicare and Medicaid coverage of PET applications in the U.S., has consistently expanded coverage for the PET, both with the types of cancer that it will pay to monitor and other imaging applications of the PET.[28] As HCFA expanded coverage, so did the HMOs. This has also led to an increase in the number of PET exams performed by each PET, which currently averages 1,000 per year[29] [8].

4. The PET technology is advantageous compared to other imaging techniques (MRI, CT, SPECT, ultrasound, etc.) for different types of imaging applications[5] than ever before (expanding searches for cancer at different organs, cardiac monitoring, brain perfusion, whole body blood flow, diabetes, lyme disease, efficient monitoring of hadron therapy, developing new drugs and studying their effect, etc.).

5. The expansion[30] of the PET is very similar to the expansion of the CT[30] [41] market two decades ago, when the number of CT scanners expanded dramatically from 2,500 to 11,500 in 15 years (see Table IV). The CT scanner effectively replaced a series of tests. Similarly, the 3D-CBS offers for the first time, a tool to recognize many health concerns. The results of the use of the PET section in the 3D-CBS will be magnified even greater than the effect of the CT, since the PET is better at recognizing cancer and it has the best features to be widely used for cardiac screening, brain scans, blood flow monitoring, etc. Because the 3D-CBS offers these same PET exams at 1/30$^{th}$ the radiation, at a faster speed, and at a lower cost, they will be even more accessible.

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25 The U.S. Census Bureau 1999 Electromedical and Irradiation Equipment reports a total market of $13.9 billion; $747.1 million is for CT scanners ($661.1 million of manufacturers' shipments of CT, with $86 million of CT scanners imported).

26 Several studies made in Holland, Germany, and Japan show that when larger machines, such as the CT scanners were introduced into the market in the '80s, the cost of treatment and diagnosis was considerably reduced by using whole-body CT to replace many x-ray examinations (see reference [6]). The study also found that hospitals with CT showed a reduction in patient stays by 8%. Additionally, at the Radiological Society of North America's (RSNA) conference in 1992 [5], the President of RSNA showed that health care costs were reduced when devices such as CT, MR or PET were used. The study compared the relative charges for different treatments in hospitals without CT, MR, or PET to those that had such devices. A few examples are the following: (a) the cost of evaluating patients with acute head injuries prior to the advent of the CT or MR was about four times as great; (b) the cost of the evaluating patients with rectal cancer prior to the use of CT or MR was about five times as great; (c) the cost of the evaluating patients with a penetrating flank injury prior to using CT or MR was about five times as great; (d) the cost of the evaluating patients with palpable breast masses prior to the advent of mammography was about three times as great; and (e) the cost of the evaluation for focal epilepsy prior to PET was about five times as great.

27 Because of the higher percentage of success of the current PET with low sensitivity in identifying cancer compared to the CT (See references [38], PET 81% success compared to CT 52% for lung study; [39] PET 95% success compared to CT 68% for colon study; [40] PET 85% success compared to 67% for breast), the new 3D-CBS with higher sensitivity and the combination of the PET and CT capability in a single detector, will identify cancer and other systemic anomalies more accurately, while providing lower radiation to the patient and reducing the number of false positives and false negatives.

28 In 1998, HCFA began reimbursement for PET detection of lung cancer; 1999, Hodgkins and non Hodgkins Lymphoma; January 2001, expanded coverage for 4 cancer applications and 2 new cancer types; and in August 2001, announcements regarding brain and coronary imaging will be made.

29 See the article in reference [8] reporting that in the year 2000, 250 PET units in the U.S. made over 250,000 examinations.

30 Historical CT data are based upon studies of the National Council on Radiation Protection and Measurements (NCRP) [41], U.S. Census Bureau, Statistical Abstract of the United States: 1999, U.S. Department of health and human services Center for disease control (CDC), Vital and Health Statistics. Historical and projected PET data based upon the studies of Diagnostic Imaging [8]. 3D-CBS projections are estimated by the author.

## 8.2 Projected market for the 3D-CBS as a "combined PET and CT machine" for diagnostic workup.

The preliminary study of the market of the scanners shown in Table IV, and Figure 14 and the need for PET and CT technology for diagnostic workups justifies the projected future market.

**TABLE IV. NUMBER OF SCANNERS USED FOR DIAGNOSTIC WORKUPS ON SYMPTOMATIC PATIENTS IN THE U.S. FROM 1980 TO 2010. (SOURCE: NCRP[30] [41], [8])**

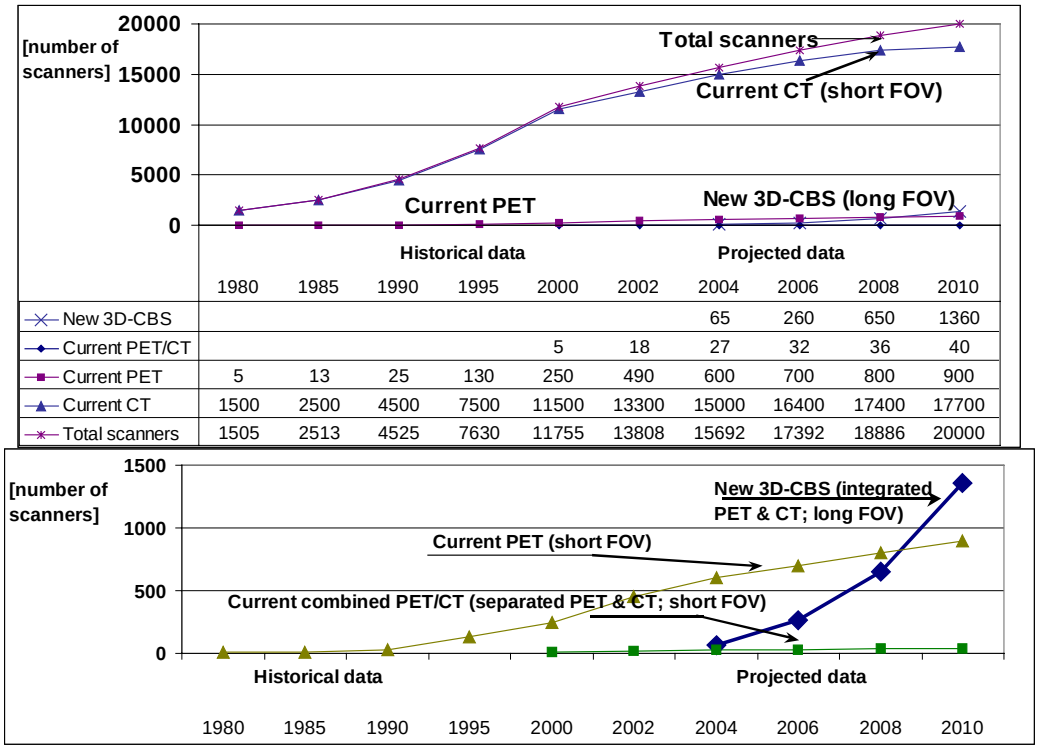
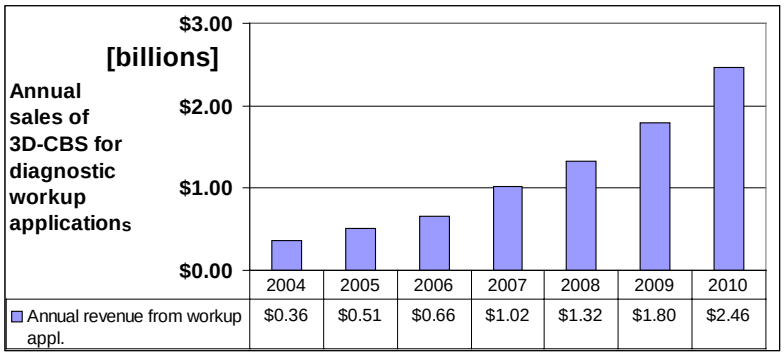



**Figure 14. Magnification of the group of scanners of Table IV with volumes up to 1,500 units (historical and projected).**

With annual growth conservatively estimated to be less than half of that of the medical imaging market, the market for diagnostic workup applications will require 1,360 3D-CBS units by the year 2010, reaching an annual volume of sales of about $2.46 billion, as shown in Table V.

The 3D-CBS would be used in both the current PET and CT scanner market because of its superior speed, resolution and accuracy (see [1], [21], [2], [3]). Its faster scan allows hospitals to examine about six times the number of patients per day[31] (see Figure 2) with PET at a reduction in marginal operating costs[32], enabling many more hospitals to afford a PET machine (when compared to the current PET).

**TABLE V PROJECTED ANNUAL REVENUES FROM THE 3D-CBS UNITS SOLD TO DIAGNOSE PEOPLE WITH SYMPTOMS.**




**Advantages of the 3D-CBS' operating costs compared to current PET, CT, etc., in diagnostic workup**

The slower scanning times of the current PETs limit their patient throughput/number of PET exams that they can perform in a year. (See Table IV). Table VI shows the difference in operating costs between the current PETs and the 3D-CBS for the same volume for the three scanners of 1,500 exams per year[31]. Note that the slower <14 cm FOV PET cannot perform more than 1,250 full 150 cm body scans[2] within the standard 2,500 operating hours per year. The ~25 cm FOV PET cannot perform more than 1,750 exams in 2,500 hours per year, while the 3D-CBS can perform 10,500 exams.

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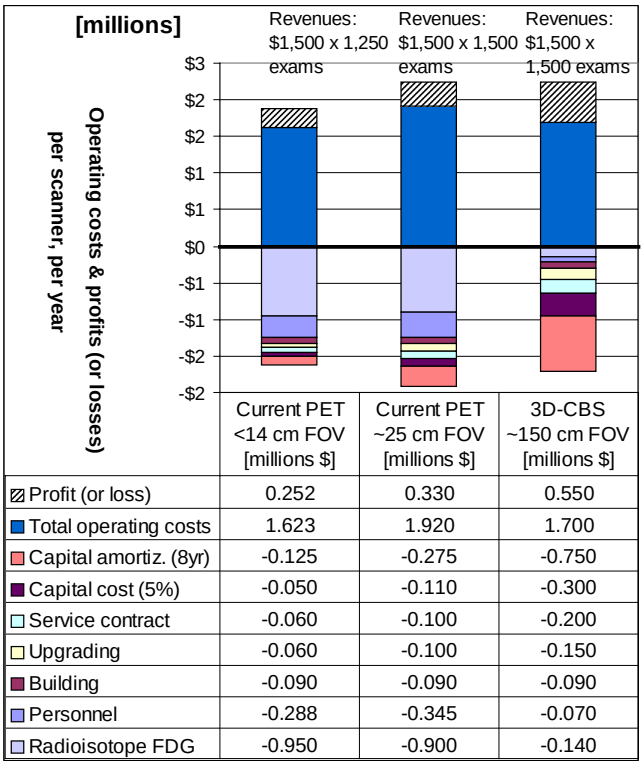
[31] This model allows 5 patients per day (10 hours/day) for the slower <14 cm FOV, 6 patients per day (9 hours/day) for the ~25 cm FOV PET, for 250 days/year, and 30 patients per day (7.5 hours/day) for the 3D-CBS, for 50 days/year. The cost of the $^{18}$F-FDG radioisotope is estimated to be $2,800/day for the 3D-CBS, $3,600/day for the ~25 cm FOV PET, and $3,800/day for the < 14 cm FOV PET because it is slower and needs a longer scanning time. (Diabetics need to use a tracer different from fluorodeoxiglucose $^{18}$F-FDG).

For the worst case scenario with a low number of examinations per year, any price above $1,500 will provide a profit to the hospital[32] (current PET examination prices range from $2,000 to $4,000).

**TABLE VI WORST CASE SCENARIO: EVEN IF THE 3D-CBS IS UNDERUTILIZED, IT HAS STILL LOWER OPERATING COSTS THAN THE CURRENT PETS (COMPARISON OF THE 3D-CBS, WHEN IT IS USED ONLY ONCE PER WEEK WITH CURRENT PET USED DAILY).**




| | Current PET <14 cm FOV [millions $] | Current PET ~25 cm FOV [millions $] | 3D-CBS ~150 cm FOV [millions $] |
|---|---|---|---|
| Profit (or loss) | 0.252 | 0.330 | 0.550 |
| Total operating costs | 1.623 | 1.920 | 1.700 |
| Capital amortiz. (8yr) | -0.125 | -0.275 | -0.750 |
| Capital cost (5%) | -0.050 | -0.110 | -0.300 |
| Service contract | -0.060 | -0.100 | -0.200 |
| Upgrading | -0.060 | -0.100 | -0.150 |
| Building | -0.090 | -0.090 | -0.090 |
| Personnel | -0.288 | -0.345 | -0.070 |
| Radioisotope FDG | -0.950 | -0.900 | -0.140 |

The costs calculated in Table VI refer to the current PET examination price (~$1,500) and to a volume of exams slightly above the average of the ~25 cm axial FOV PET.[12] The significantly faster 3D-CBS could scan 1,500 patients in less than 50 days, while the current PET would require 250 days! The speed of the 3D-CBS scanner and its higher sensitivity requires only 1/30th of the current PETs' radiation and saves costs of personnel and radioisotopes, which compensate for the higher cost of the amortization of the unit, the service contract, and the upgrades[33].

# 9 WHAT KIND OF DOORS DOES THIS NEW DISCOVERY OPEN TO BENEFIT HEALTH CARE?

processing of the data from the detector, permits it to capture more photons, and lower the radiation that must be administered to the patients.

This discovery allows the use of normal crystals (available for more than 25 years) to build a device with performance improved to the level of permitting its use annually with no risk to asymptomatic people. This new architecture together with other innovations of the 3D-CBS limits the longer dead-time of the BGO and CSI crystals to a small area where the photon hits the detector. The overall efficiency is not seriously compromised, as it is with the electronics of the current PET and CT.

This is an enormous advantage that will change the way medicine is practiced. In the past, the limited worldwide production capability of fast crystals, such as LSO, and the high radiation dosage that must be administered to a patient were two barriers that have been broken with the 3D-CBS.

New fast and economical crystals that are being developed along with the LSO, which we've had for more than 10 years, augment the production capability of PET. However, with the discoveries set forth in this document, the less expensive and more abundant crystals (such BGO and CSI) can be used to satisfy the great need for diagnostic devices worldwide.

Although the novel 3D-Flow electronics of the 3D-CBS can cope with the fastest crystals, the difference in overall performance between fast and slow crystal detectors in the 3D-CBS will not be as great as it is now using the electronics of the current PET.

The most important new uses this device makes possible are:

1. the monitoring of the effect of the drugs during the staging of cancer or other diseases (repetitive exams on the patients are now possible without putting the patient at the current high radiation risks);
2. accurate measurements of the effects of new drugs; and
3. annual screening for cancer and other systemic anomalies which will be an important contribution to the role of preventive medicine.

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[32] Personnel costs have been calculated from to the costs of Table 5-2 on page 37 of [4]; ½ MD, 2 technologists and administrators for the >14 cm FOV for 5 days/week; ½ MD, 2 ½ technologists and administrators for the 25 cm FOV for 5 days/week; 1 MD, 2 ½ technologists and administrators 1 day/week for the 3D-CBS.

[33] The operating costs involved in both the current PET and the 3D-CBS, may vary substantially from different location. Figures conservatively use the highest costs. Source of costs for the U.S. comes from discussions with radioisotope manufacturers and users, hospital administrators, while for Europe the reference [4] was used. The capital amortization for the 3D-CBS is $6,000,000/8years = $750,000/year, the PET with ~25 cm FOV is $2.2M/8years = $275,000/year, while the PET with <14 cm FOV is $1M/8years = $125,000/year. The capital cost for the 3D-CBS is calculated as 5% of $6,000,000. The cost of the building (estimated $1,000,000) where the 3D-CBS is installed is estimated to be $40,000 for capital cost, $25,000 for depreciation (40 years), and $25,000 for maintenance, including power (See also Table 5-2 of [4] for similar calculation).

## 9.1 Projected market for the 3D-CBS for preventive health care as an annual screening device.

Besides the current market for scanners for patients who manifest symptoms of anomalies, a new market for preventive health care on the asymptomatic (people who currently look and feel healthy) population is now possible because of the lower radiation requirements by the 3D-CBS scanner (see Table VIII).

While it is difficult to estimate the market of the first two of the above-mentioned new areas of application. The third, however, the screening of the asymptomatic population, can be estimated for the U.S. by calculating how many 3D-CBS units wouldl be necessary to screen that population considered to be at high risk.

At first, those over 50 years of age will be considered at higher risk. When a sufficient number of 3D-CBS units become available to screen most of the population over 50, screening could be extended to the population at next lower risk, i.e., those aged 45; and successively at 40, and then 35 years of age.

Savings can be estimated, as well, by comparing the aggregate cost of current screening procedures (see Table XI) which cover a limited number of organs of the body, to that of one whole-body screening with the 3D-CBS.

This additional market of the 3D-CBS is estimated to be $2.54 billion annually by the year 2010 (see Table VII). It would require 1,464 scanners by 2010 in order to scan 15% of the U.S. population over 50 years old. This is assuming conservatively that each 3D-CBS scanner will screen 10,500 patients/year. In the event of non-optimal utilization of the capabilities of the 3D-CBS, the 3D-CBS market will be larger and more scanners will be needed (e.g., if each 3D-CBS performs only 5,000 screenings per year, twice as many scanners will be needed for screening the same percentage of the U.S. population).

The growth projections of the 3D-CBS are conservatively based on less than half of the historical growth of the market for CT scans. Between 1985-2000, the number of CTs increased by over 9,000 units (see Table IV); this should be compared to the projected growth of the 3D-CBS (as shown in Table VIII and Table VII) of only 1,000 units within 5 years (the high efficiency 3D-CBS can perform the volume of work equivalent to the output of several separate PET or CT units).

Notice that the number of 3D-CBS scans (for cancer screening, on healthy patients) does not exceed 16 million until 2010 (See Table XIV). To put these numbers in perspective, scanning 3.34% of our targeted U.S. population (about 3 million scans) in 2006 is not a large number compared to the current use of imaging devices; in 2000, in the U.S. alone, there were over 30 million CT scans, which were restricted to the diagnostic workup of patients who are showing symptoms of being ill (See Table XIV and footnote[18]).

**TABLE VII PROJECTED ANNUAL MARKET FOR THE 3D-CBS SCANNERS SOLD FOR CANCER SCREENING OF THE ASYMPTOMATIC POPULATION OVER 50 YEARS OLD.**

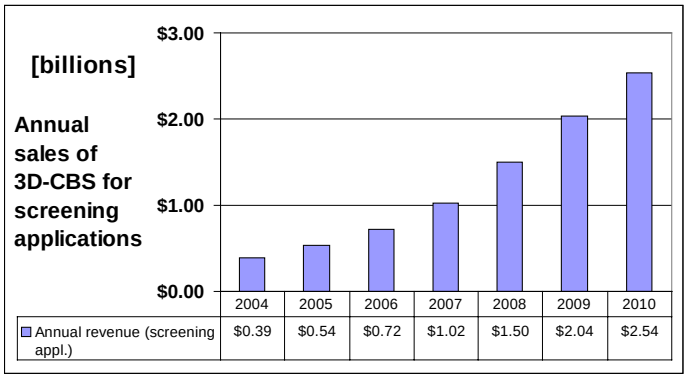
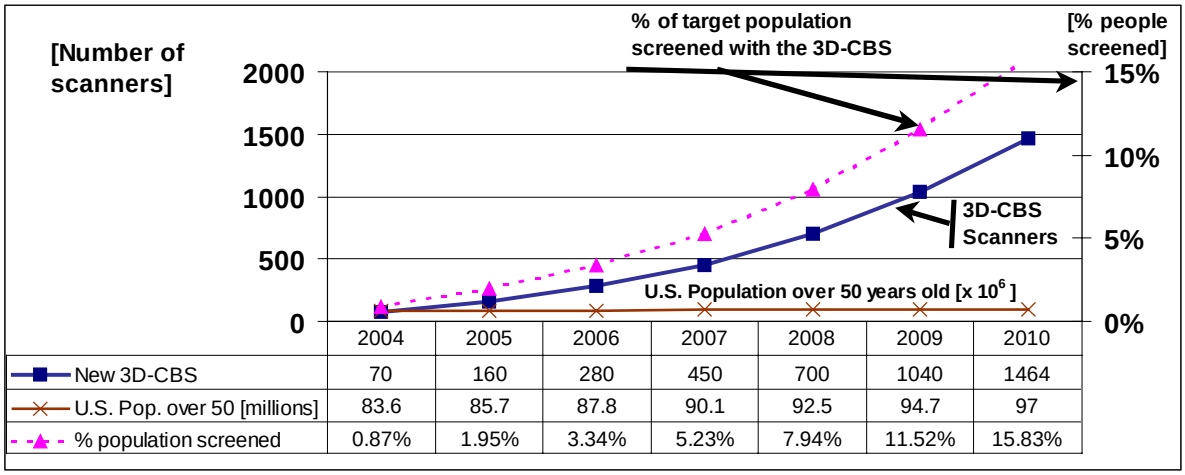



**TABLE VIII NEW 3D-CBS SCANNER MARKET: PROJECTED GROWTH AND TOTAL NUMBER OF 3D-CBS SCANNERS NEEDED FOR THE ANNUAL SCREENING OF ONLY 15% OF THE U.S. POPULATION OVER 50 YEARS OLD BY 2010.**




| | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|
| New 3D-CBS | 70 | 160 | 280 | 450 | 700 | 1040 | 1464 |
| U.S. Pop. over 50 [millions] | 83.6 | 85.7 | 87.8 | 90.1 | 92.5 | 94.7 | 97 |
| % population screened | 0.87% | 1.95% | 3.34% | 5.23% | 7.94% | 11.52% | 15.83% |

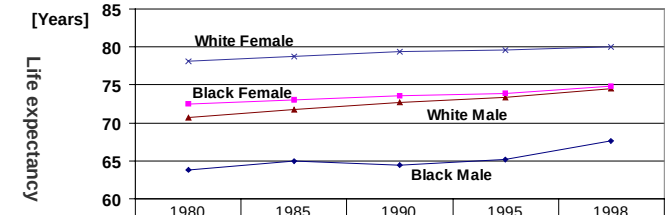
Every year in the U.S., an estimated 1.2 million new cases of cancer are diagnosed and more than 550,000 people die from various forms of cancer (840,000 in Europe). Out of a total number of 2,337,256 deaths in the US in 1998, the highest cause of deaths for the group 45-64 years old was cancer (one out of three deaths), from which 132,771 people died that year (see Figure 15). Second highest cause of deaths for the same age group was 100,124 people who died from diseases of heart [42]. Both, cancer and heart disease were 60% of the total 380,203 causes of deaths in the age group 45-64 in 1998.

It is obvious that one would expect that the impact, in terms of reduced mortality in this age group, which is below the life expectancy (see Table IX) were immense if people were treated sooner by early detection from annual screening of the entire body. This can occur with advances in technology, such as the 3D-CBS, that permits a lower radiation dosage and provides better quality images at lower examination costs for the screening of cancer, heart and other systemic anomalies.

Death rate have consistently fallen for cancer for which intense screening program have been developed. Although screening the entire body instead of a single organ (breast, prostate, etc.), expects to provide greater results to all people receiving the screening, for optimal risk management it is easier to measure the results from the screening an age group below life expectancy (such as 45-64) that has high cancer incidence.

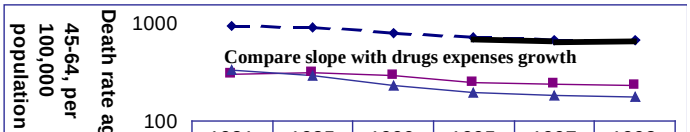
Table X shows that during the past year there were more improvements in reducing the death rate (within the age group 45-64) caused by heart (e.g., from 327 in 1981 to 173 in 1998 per 100,000 population) rather than the one caused by cancer (e.g., from 304 in 1981 to 229 in 1998 per 100,000 population). (It doesn't seem that the high increase in drug expenditures from 1995 to 1999 provided benefits in additional reduction of the death rate for the same period. See Figure 3).

**TABLE IX. LIFE EXPECTANCY BY RACE IN THE UNITED STATES FROM 1980-1998 (SOURCE: NATIONAL VITAL STAT. REPORTS [43])**




| | 1980 | 1985 | 1990 | 1995 | 1998 |
|---|---|---|---|---|---|
| White Male | 70.7 | 71.8 | 72.7 | 73.4 | 74.5 |
| White Female | 78.1 | 78.7 | 79.4 | 79.6 | 80 |
| Black Male | 63.8 | 65 | 64.5 | 65.2 | 67.6 |
| Black Female | 72.5 | 73 | 73.6 | 73.9 | 74.8 |

**TABLE X. DEATH RATE IN 45-64 AGE GROUP IN U.S. FROM 1981 TO 1998 PER 100,000 POPULATION (SOURCE: NVSR [44], [42])**




| | 1981 | 1985 | 1990 | 1995 | 1997 | 1998 |
|---|---|---|---|---|---|---|
| all causes | 942 | 910 | 800 | 720 | 680 | 664 |
| cancer | 304 | 310 | 290 | 250 | 238 | 232 |
| heart | 327 | 290 | 230 | 196 | 183 | 175 |

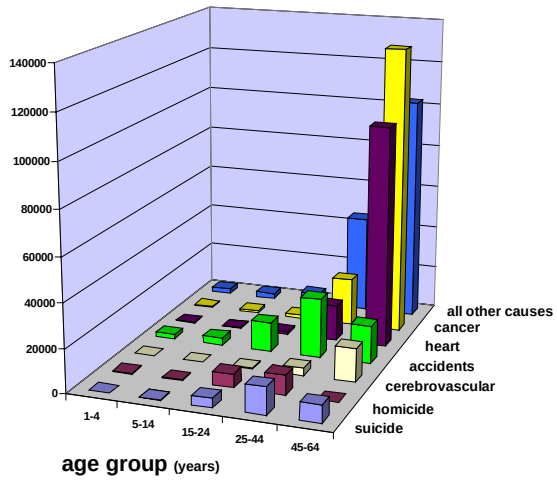



**Figure 15. Deaths in United States in 1998 by cause and by age group. (Source: National Vital Statistic Reports [42]).**

## 9.2 Advantages of the 3D-CBS' low operating cost.

The examination price of the 3D-CBS is competitive with many of the costs for individual, region-specific exams used to screen people annually (as shown in Table XI[34]), and offers coverage of the whole body at once, instead of a single organ in individual exams. In addition, the current PET examinations cannot be repeated annually because of the high radiation dosage required.

Table XII shows the operational costs[35] and profits (or losses) of operating the scanners at maximum throughput when the examination price is $300/exam (cost floor of the 3D-CBS). The 3D-CBS has a profit of ~$160,000/year.[36], the PET with ~25 cm axial FOV has a loss of ~$1,543,000/year, while the PET with <14 cm axial FOV has a loss of ~$1,292,000/year.

34 Prices of the list of procedures of Table XI have been compiled in the Dallas area during the year 2000 and they may vary by different location.

35 This assumes 7 patients per day for the >14 cm FOV and ~25 cm FOV PET, for 250 days/year and 42 patients per day for the 3D-CBS, for 250 days/year. The cost of the $^{18}$F-FDG radioisotope is estimated to be the same ($3,800/day) for the three scanners. (Diabetics need to use a tracer different from fluorodeoxiglucose $^{18}$FDG). The comparisons between the three types of scanners fairly assume that all three are operating for the same number of hours. The personnel costs have been base on Table 5-2 on page 37 of [4]: ½ MD, 2 technologists/administrators for the >14 cm FOV for 5 days/week; ½ MD, 2 ½ technol./admin. for the ~25 cm FOV for 5 days/week; 1 MD, 2 ½ technologists/administrators for the 3D-CBS.

36 The capability of scanning 10,500 people per year assumes that each 3D-CBS exam last 15 to 20 minutes, with 3 to 4 minutes of scanning time (See Figure 2). Although it is commonly known that the CT scan averages only 4 minutes/patient, many times the CT scanner is used with a contrast agent. For these types of procedures, the examination may require two or more scans. A 3D-CBS with both examinations (that occur at the same time) requiring only 3-4 minutes and a throughput of 3 to 4 patients per hour is not overestimated.

A comparison of the costs and efficiencies of the 3D-CBS with other methods (see Table XI) of cancer screening reveals that a one stop, noninvasive, whole body cancer screening machine is much more cost effective.

**TABLE XI LIST OF THE APPROXIMATE[34] COSTS OF SOME CURRENT PROCEDURES AND/OR EXAMINATIONS FOR CANCER SCREENING.**

| | | |
|---|---|---|
| **Breast cancer** | Mammogram | $80-$200 |
| | Sonogram | $250-400 |
| | MRI (with contrast ag.) | $900-1400 |
| | Biopsy | $500-700 |
| **Colon cancer** | FOBT | $20-65 |
| | Barium Enema (Fluoro) | $600-800 |
| | Sigmoidoscopy | $300-500 |
| | Colonoscopy | $1500-2000 |
| **Gynecological cancer** | Uterine cervix: Pap smear | $40-100 |
| | Sonogram | $450-600 |
| | Uterus corpus (biopsy) | $500-1500 |
| **Lung cancer** | Chest X-ray | $50-300 |
| | Broncoscopy | $1200-1600 |
| | CT chest (with contrast) | $800-1200 |
| | Biopsy | $700-1200 |
| **Prostate cancer** | Digital Rectal test | ~$100 |
| | Prostate Specific Antigen | $25-120 |
| | Sonogram | $400-500 |
| | Biopsy | $500-600 |
| **Lymphoma cancer** | CT (with contrast ag.) | $600-1200 |
| | MRI (with contrast ag.) | $1800-4000 |
| | Biopsy | $1000-1600 |
| **Brain cancer** | MRI (with contrast ag.) | $1000-2500 |
| | CT (with contrast ag.) | $500-1800 |

**TABLE XII COMPARISON OF OPERATING COSTS WHEN SCANNERS ARE USED AT THEIR MAXIMUM THROUGHPUT, AT THE EXAMINATION PRICE FLOOR OF THE 3D-CBS ($300/EXAM). (SOURCE[35, 36] [4])**

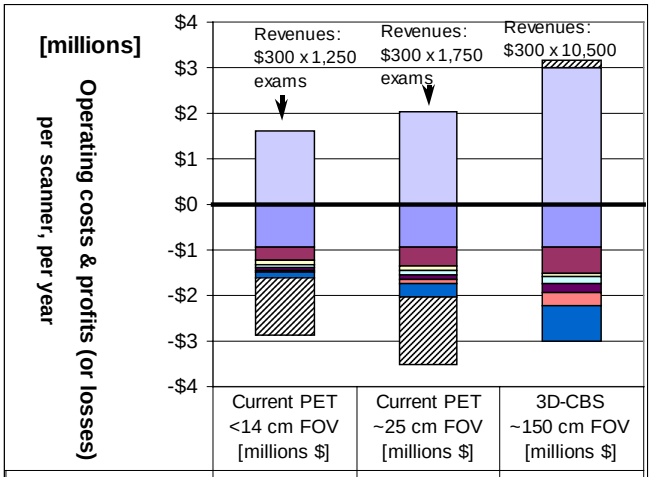
Although PET technology is ideal, it was not included in Table XI because its high radiation dosage precludes FDA approval for annual examination on asymptomatic people. The 3D-CBS' requirement of only 1/30$^{th}$ of the radiation dosage remedies this problem. The 3D-CBS offers a cost effective, non-invasive, whole-body scan that replaces (or avoids the need) of most of the procedures in Table XI.

The price of the annual 3D-CBS screening examination for cancer and other anomalies will be in between the price floor of the 3D-CBS of approximately $300 per exam as shown in Table XII and the current PET price floor which now reaches $1,300 (at higher volumes compared to the previous $1,500 of Table VI) per exam, as shown in Table XIII.

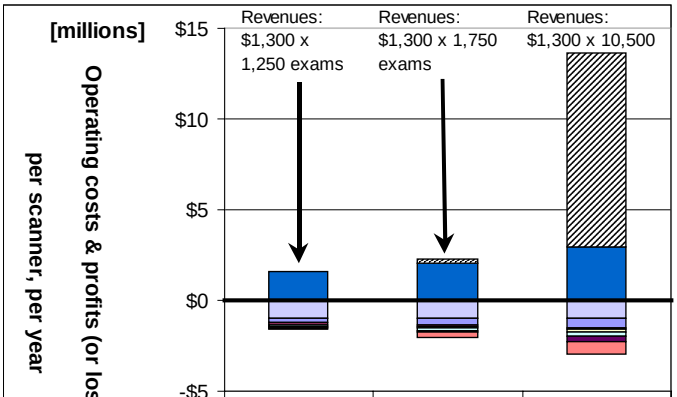
The 3D-CBS' examination price for greater coverage of the body is still very competitive with the cost of the current screening exams reimbursed by the government (Pap smear, mammogram, PSA, etc.) and much less than the group of the current screening examinations paid by the wealthiest (the cost of the previous exams reimbursed by the government in addition to colonoscopy, CT, Sonogram, MRI, and Biopsy can easily total over $5,000 per year).

Table XIII shows the operational costs[35] and profits (or losses) for a maximum throughput of the scanners when the examination price is $1,300/exam (cost floor of the current PET). The 3D-CBS has a profit of about $10,660,000/year[36], the PET with ~25 cm axial FOV has a profit of about $213,000/year, while the PET with <14 cm axial FOV has a profit of about $22,000/year.

**TABLE XIII COMPARISON OF OPERATING COSTS WHEN SCANNERS ARE USED AT THEIR MAXIMUM THROUGHPUT, AT THE EXAMINATION PRICE FLOOR OF THE CURRENT PET ($1,300/EXAM). (SOURCE[35, 36] [4]).**




| | Current PET <14 cm FOV [millions $] | Current PET ~25 cm FOV [millions $] | 3D-CBS ~150 cm FOV [millions $] |
|---|---|---|---|
| Profit (or loss) | -$1.248 | -$1.503 | $0.160 |
| Total operating costs | $1.623 | $2.028 | $2.990 |
| Capital amortiz. (8yr) | -$0.125 | -$0.275 | -$0.750 |
| Capital cost (5%) | -$0.050 | -$0.110 | -$0.300 |
| Service contract | -$0.060 | -$0.100 | -$0.200 |
| Upgrading | -$0.060 | -$0.100 | -$0.150 |
| Building | -$0.090 | -$0.090 | -$0.090 |
| Personnel | -$0.288 | -$0.403 | -$0.550 |
| Radioisotope FDG | -$0.950 | -$0.950 | -$0.950 |




| | Current PET <14 cm FOV [millions $] | Current PET ~25 cm FOV [millions $] | 3D-CBS ~150 cm FOV [millions $] |
|---|---|---|---|
| Profit (or loss) | $0.002 | $0.247 | $10.660 |
| Total operating costs | $1.623 | $2.028 | $2.990 |
| Capital amortiz. (8yr) | -$0.125 | -$0.275 | -$0.750 |
| Capital cost (5%) | -$0.050 | -$0.110 | -$0.300 |
| Service contract | -$0.060 | -$0.100 | -$0.200 |
| Upgrading | -$0.060 | -$0.100 | -$0.150 |
| Building | -$0.090 | -$0.090 | -$0.090 |
| Personnel | -$0.288 | -$0.403 | -$0.550 |
| Radioisotope FDG | -$0.950 | -$0.950 | -$0.950 |

# 10 PROJECTED NUMBER OF EXAMINATIONS BY DIFFERENT SCANNERS FROM 2004 TO 2010

Table XIV shows the projected number of examinations by different scanning machines by the year 2010, compared to the current approximate 30 million examinations per year performed with CT scan.

The combination of revenue for diagnostic workup (see Table V) and cancer screening (see Table VII) projects a total 3D-CBS market of about $5 billion by 2010.

In the short term, the 3D-CBS will be used primarily for diagnostic workup on symptomatic patients, because it can offer both PET and CT quality at a CT price.

For the additional new market of screening, the 3D-CBS offers the advantage of being less expensive and less invasive than other forms of screening, and it can do all of the screening at once, instead of several separate tests. Over a period of time, the market for the 3D-CBS as a diagnostic workup tool will be small compared to the larger market for the 3D-CBS as an annual cancer screening machine.

It is important to note that even the projections for 2010 are not bold exaggerations[7]; in 2000, there were over 30 million CT scans performed. In the graph charting for screening (see Table XIV), it is only predicted that there will be 10 million 3D-CBS scans for workups and 15 million for screening by 2010. These estimates are based on the assumption that the 3D-CBS will have less than one fourth of the U.S. CT market by 2010, and will screen annually by 2010 only 15% of the U.S. population over 50. Because the U.S. market is less than one third the entire world market and because the market in the U.S. is actually bigger than the one estimated in this study[7], the total annual market could be over $50 billion for the 3D-CBS.

The average number of examinations per scanner per year is estimated at 2,600 exams per year per CT scanner; 1,250 exams per year[31] per each current PET scanner and current CT/PET scanner; and 7,500 exams per year per each 3D-CBS scanner used for diagnostic workups and 10,500/exams per year[36] for each 3D-CBS used for annual screening35.

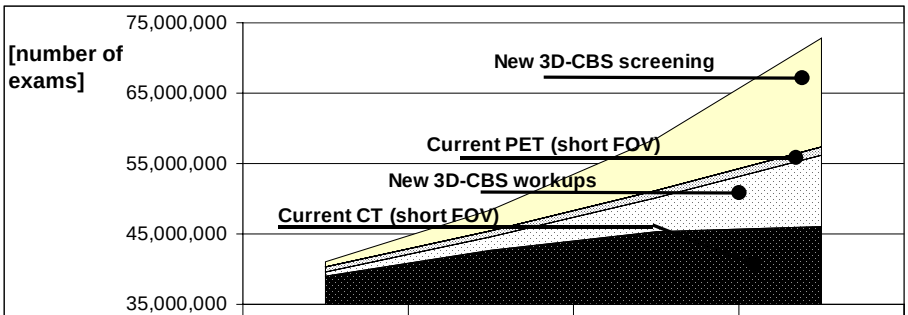
# 11 AVAILABILITY OF THE MATERIAL FOR MASS PRODUCTION OF 3D-CBS

The use of the simpler but higher performance electronics of the 3D-CBS makes it possible to produce the 3D-CBS in large quantities using the most common parts, rather than being limited, as is the case in the current PET. Although research continues for an ideal[3], economical, and readily available fast crystal, there is also the desire to assist the patients who will benefit from the potential of the combined technologies of the CT and PET. For this reason, one should base a design on parts which are readily available at a reasonable price now, and the design should also be upgradable to faster crystals when they become available.

An additional strength of the 3D-CBS design, therefore, is that it can use the fast LSO crystals but can also achieve improved performance now, while using the cheaper, slower BGO, CsI, or other slower crystals, which are currently available in abundance.

Approximately 150 $m^3$ of scintillating crystals (calculated as ~50,000 $cm^3$ per 3D-CBS scanner) would be needed for the U.S. market alone during the next nine years in order to achieve the goal of 3,000 3D-CBS units. (See Figure 11 of [2], or Section 18 of [1]). This number of units will allow the scanning of about 25 million people per year by the year 2010 (which is still only about half of what the CT will be scanning during the same year. See Table XIV). If the market for medical imaging outside the U.S. advances as well, as has been the case in the past, more than 500 $m^3$ scintillating crystals will be needed worldwide by 2010. While the BGO and CsI crystals are available in good supply from multiple sources, LSO has had a total production capability during the past 15 years of less than 5 $m^3$.

**TABLE XIV. PROJECTED NUMBER OF EXAMINATIONS BY DIFFERENT SCANNING MACHINES BY THE YEAR 2010.**




| | 2004 | 2006 | 2008 | 2010 |
|---|---|---|---|---|
| New 3D-CBS screening | 735,000 | 2,940,000 | 7,350,000 | 15,372,000 |
| Current CT/PET | 33,750 | 40,000 | 45,000 | 50,000 |
| Current PET | 750,000 | 875,000 | 1,000,000 | 1,125,000 |
| New 3D-CBS workups | 487,500 | 1,950,000 | 4,875,000 | 10,200,000 |
| Current CT | 39,000,000 | 42,640,000 | 45,240,000 | 46,020,000 |

# 12 WHO WILL BENEFIT FROM THE 3D-CBS?

## 12.1 Patients and people with asymptomatic conditions

It is obvious that the patient has only to gain from the project described in this article, and he will be the greatest beneficiary of the better technology, which, in reducing the number of false positives and false negatives, produces a better image in less time, the faster scanning requiring only about 1/30 of radiation dosage, and all this at only 1/10 of the cost.

Because there are many cases where the current PET already surpassed the other imaging techniques, these testimonies are destined to multiply in number and impact when the 3D-CBS (with higher efficiency and combining features of two of the best medical imaging instruments) is fully utilized.

## 12.2 Hospitals and physicians

Hospitals will benefit from the 3D-CBS in many ways, some of which are:

- Lower examination cost to the hospitals (less than $300 with the 3D-CBS)
- The hospital and its physicians will be able to offer the highest quality image and best medical opinions based upon the observable phenomena.
- The lower radiation dosage will also allow the hospital to expand its cancer research, staging, and monitoring while decreasing the radiation exposure to the patients from the current levels.
- Hospitals will be able to utilize their staff and resources more economically, with medical staff time resulting in approximately ten more scans per man-hour than with the slow scanning time of the current PET.
- The hospital will finally have a machine that has a capacity beyond the hospital's utilization needs: the 3D-CBS can scan up to 10,000 patients per year compared to the current PETs' 750 to 1,000 patients per year, and hospitals can absorb the operating costs and amortization costs of the 3D-CBS, even if they only utilize the machine for 1,000 PET exams per year.

## 12.3 Investors

Investors will have extensive lead time before competitors are able to build a product that can perform an examination at the price of $300. A prompt introduction into the market of the 3D-CBS will maximize the lead time, provide a good return on their investment and enable the investor to set the price of the machine and of the examination, as shown in Figure 1. Hospitals that have purchased the current PET cannot compete with the same low examination price in 8 years required to amortize the capital they have spent.

The 3D-CBS, even though more expensive than current PET, will be advantageous to the buyer (hospital or Mobile PET), because even at a lower cost per examination their daily revenues will be higher and financing will be easily available (provided that the number of examinations performed per day also rises).

Both the investors in the manufacturing of the 3D-CBS and the investors in companies or hospitals operating the machine will realize the cost-effectiveness and will benefit financially from the 3D-CBS.

The hospital and the Mobile PET will purchase the 3D-CBS not only because of its better performance but also because the benefits to be derived from the innovations described in this article compensate the investors for the increased cost of a PET with a longer FOV. It will also provide the additional economic benefit that the market will share between more profit and a lower examination price. Lowering the examination price is also beneficial because it makes the examination accessible to more people, thus it increases the usage of the 3D-CBS, which again increases the profit.

## 12.4 Researchers in cancer, heart disease, and new pharmaceutical products.

The new possibilities of the 3D-CBS whole-body scanner with a lower radiation requirements open new avenues in medical research, because with it annual screenings are safe; there is no longer the hazard of high radiation. Much new research will be possible: longitudinal data from annual screenings of one patient will show incremental change; comparative data, such as scans of all family members at different ages will add to an understanding of the inheritance factors in risk of cancer and heart disease; and parallel studies of various national groups can be used to investigate the influences of the environment or nutrition. These and more areas of research will help improve disease prevention.

The availability of an accurate whole-body scan device, such as the 3D-CBS, that encircles most of the radioactive area of the patient's body allows accurate dosimetric measurements. The high sensitivity of the 3D-CBS is ideal for the research and development of new pharmaceutical components.

The high sensitivity and accurate measurement of the whole-body 3D-CBS will be ideal for hadron therapy, where one isotope is used to kill the cancer and another isotope is used to monitor it by means of photon emissions in opposite directions, the effect of the hadron therapy.

Also see all the potential new applications listed in Section 9 of this article where PET technology could be beneficial.

## 12.5 Insurance companies

Insurance companies will find that the 3D-CBS will save many expensive procedures[26] and that patients will have shorter hospital stays[1].

The savings to insurance companies and HMOs will be several-fold. First, health insurers will benefit from the availability of one safe, whole-body examination that costs significantly less than the aggregate cost of several existing

exams, which they now approve. Second, given that early detection has been proven to lead to shorter patient stays and increased survival rates, there will be significant cost savings in these areas, as is indicated in Japan and other countries where scans are more prevalent. The desire of the insurance companies to save money on the cost of the 3D-CBS scans will synergize with the investors' desire to sell the maximum number of machines and the hospitals' need to utilize the machine efficiently and maximize per-day patient throughput (so as to save on the cost of the radioisotope).

### 12.6 Government administrators

Government administrators will have a great opportunity to create a benefit for the population by reducing the radiation to patients and improving health care thus saving more people's lives. Further, the 3D-CBS helps reduce expenditures for health care, which is also an important goal.

The cost of health care last year in the U.S. was over $1.2 trillion. The National Institutes of Health, National Cancer Institute, studies reported that cancer alone cost $107 billion per year in the U.S; $37 billion for direct medical costs, $11 billion for morbidity costs (cost of loss of productivity), and $59 billion for mortality costs. Early detection, in addition to providing a better quality of life for people, will allow the patient to avoid expensive procedures typical when the cancer is found in its advanced development or is metastasized in the body. A practical, affordable device affording early detection would offer savings in the big picture of global health care cost reduction as well.

## 13 WHO MAY NOT WANT THE 3D-CBS?

It is hard to believe that there could be someone who would not want the 3D-CBS. However, any carefully considered arguments for not promoting this project are urgently invited by the author. Timely discussion will keep the project moving forward. Delaying it would be to further delay benefits to patients .

It is perfectly understandable that a hospital that just purchased a PET with short FOV, with an efficiency of 2 photons out of 10,000 captured, as well as the PET manufacturers, may feel disadvantaged in having just missed out on an innovation and many hope that Table I, Table VI, Table XII, and Table XIII are wrong. However, the cost of operation of the device reported in the referenced tables are conservative and are similar to those compiled by a large hospital in Zurich that has been operating PET for several years and reported in [4].

Objections to the author's claims, such as that (a) the logic (and description of the detailed implementation) of the sequentially implemented 3D-Flow parallel processing system is flawed, that (b) a DSP on each channel to improve signal-to-noise ratio is useless, or that (c) all other innovations of the 3D-CBS do not allow an increase of the FOV in a cost effective manner, cannot be sustained by the persons opposed to this project. Conversely, it is clear that current PET do not rebuild the total energy of the photon, that they have detector boundaries, and that they cannot perform interpolation among all neighboring signals, thus failing to obtain good spatial resolution. On the other end, it is obvious from Figure 12 that (a) a detector with a longer FOV can capture more photons from a single organ, and (b) the 3D-CBS described in this (and in the referenced) documents can solve all of the above limitations.

Resistance to change occurs any time there is innovation. The worldwide market for scanners, presently about $50 billion, leaves room for many alternative designs and can provide benefits to many people, but ultimately and especially to the grass-roots consumer, the patient.

It is to be hoped that hospitals that just purchased a PET and the companies that manufactured them **will not deny or ignore the evidence and will make it possible to move on soon.** Mutual collaboration will advance the cause of health care and ultimately benefit all of us.

## 14 ACTION PLAN FOR SPREADING BENEFITS OF 3D-CBS

### 14.1 Interested in defeating cancer, heart disease, improving the quality of life and life expectancy? Then don't settle for less; cooperate for the implementation of the 3D-CBS.

Do not settle for incremental improvements in efficiency of medical imaging instruments every 5 years, as has occurred in the past 25 years. This article and the references [1], [2], [3], provide the blueprint for how to get an improvement in efficiency of several orders of magnitude right now in a single step with today's technology. Do not take for granted that the claims for such increased improvement of several orders of magnitude cannot be achieved. Obtain the details, and if you have any doubts about them or any questions on any section of the project, please write to the address provided at the end of this document. A collection of questions with the associated answers will be made available on the web at 3D-Computing.com. This should hasten the development of the highly efficient 3D-CBS. (See. (See Figure 16).

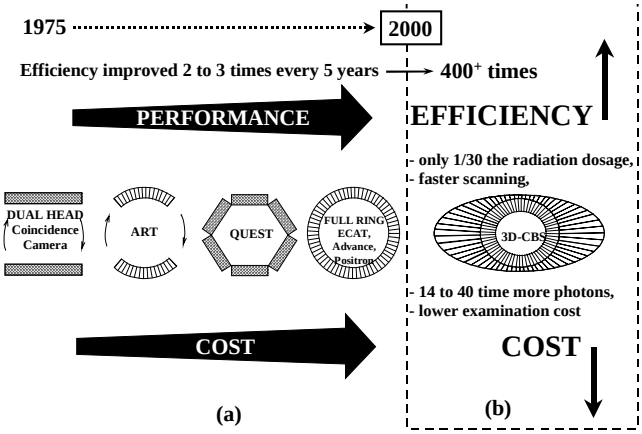



**Figure 16. The evolution of positron imaging systems (original source of the figure [20], on the left). Section (a) shows the evolution of the PET using the past and current approach, while Section (b) shows the improvements achievable with the new 3D-CBS described in this document.**

Given the potential health benefits of significantly increasing the methods of detecting cancer at an early stage, the worst thing that could happen to this article or project is that it should stall due to inaction. A claim as weighty as the claims of the advantages of the technology of the 3D-CBS in this article ought to be reviewed and discussed. Even a small response of support, further inquiry, or a critical analysis of a claim significantly aids this project. It is essential to continue the dialogue to facilitate a common understanding of this project.

**TABLE XV. SUMMARY OF THE ADVANTAGES AND DIFFERENCES OF THE 3D-CBS COMPARED TO THE CURRENT PET.**

| Current PET | New 3D-CBS | Advantages/ differences |
|---|---|---|
| Efficiency: 0.007% to 0.025% | Efficiency: > 10% | Improved 400$^{+}$ times |
| Image Quality: POOR | Image Quality: VERY GOOD | Improved 14 to 40 times |
| Radiation to the patient: 1100 mrem to 1600 mrem | Radiation to the patient: 25 to 45 mrem | Reduced to 1/30 |
| Cost of Equipment $2 to $3 million | Cost of Equipment ~ $6 million | Increased from 2 to 3 times |
| Examination Cost: $2,000 to $3,000 (10 mCi of FDG tracer = $600 55 minutes scan time) | Examination Cost: $300 to $400 (0.4 mCi of FDG tracer = $60 4 minutes scan time) | Reduced to 1/10 |
| Annual Screening? NO (because exposure to high radiation prohibits annual scan) | Annual Screening? YES (because exposure to low radiation permits annual scan) | |

## 14.2 Web site where questions, answers and different opinions will be posted:

www.3D-Computing.com

**Request for comment (RFC):**

This is a complex project that requires the energy and involvement of experienced individuals. For those readers who would like to assist this project but are unable to do so because of other time commitments or valuable endeavors, the author respectfully requests that the reader make a response in one of the following four ways:

1. The author will gratefully appreciate any comments or technical criticisms, which will aid him in ascertaining where some area may need further innovations or how better to explain the technology.
2. Please indicate any areas of interest/focus that you would like to know more about.
3. Please indicate any areas where you can be of assistance, or any alliances or other parties that may be interested in this project.
4. If nothing else, a comment of support will be appreciated.

Please send your comment to:

info@3d-computing.com

If you are interested in additional technical information on this project, please find the article [2] presented at the IEEE conference in Lyon, France on October 2000, at www.3d-computing.com/pb/ieee2000-563.pdf.

Additional details on the PET section of the 3D-CBS can be found in the book [1] at amazon.com.

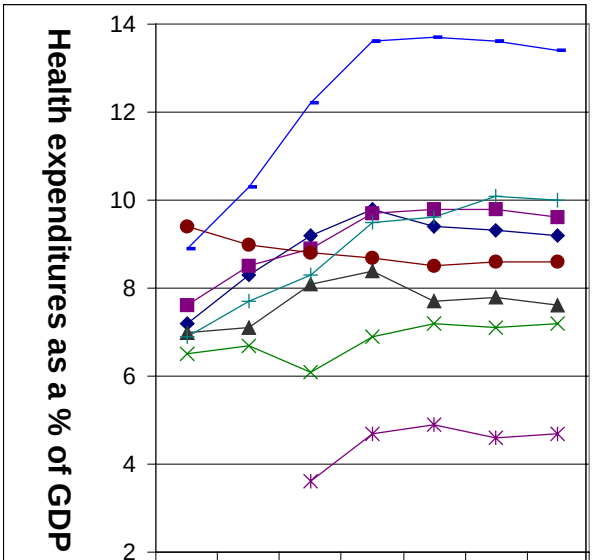
Additional information on the technology of the unique architecture which breaks through the efficiency barrier of current medical imaging instrumentation in capturing more photons [21] has been refereed and published by Elsevier in the scientific journal: Nuclear Instrument and Methods in Physics research and is available at the technical libraries of universities.

# APPENDIX A. VERIFICATION THAT INVESTMENT IN THE 3D-CBS IS JUSTIFIED

## Appendix A.1. World-wide health care expense

The expense for health care as a percentage of the gross domestic product (GDP) of a few countries of the world is reported in Table XVI.

**TABLE XVI. HEALTH CARE EXPENDITURES AS A SHARE OF THE GROSS DOMESTIC PRODUCT IN DIFFERENT COUNTRIES FROM 1980 TO 1997 (SOURCES[37]).**




| | 1980 | 1985 | 1990 | 1994 | 1995 | 1996 | 1997 |
|---|---|---|---|---|---|---|---|
| Canada | 7.2 | 8.3 | 9.2 | 9.8 | 9.4 | 9.3 | 9.2 |
| France | 7.6 | 8.5 | 8.9 | 9.7 | 9.8 | 9.8 | 9.6 |
| Italy | 7 | 7.1 | 8.1 | 8.4 | 7.7 | 7.8 | 7.6 |
| Japan | 6.5 | 6.7 | 6.1 | 6.9 | 7.2 | 7.1 | 7.2 |
| Mexico | | | 3.6 | 4.7 | 4.9 | 4.6 | 4.7 |
| Sweden | 9.4 | 9 | 8.8 | 8.7 | 8.5 | 8.6 | 8.6 |
| Switzerland | 6.9 | 7.7 | 8.3 | 9.5 | 9.6 | 10.1 | 10 |
| USA | 8.9 | 10.3 | 12.2 | 13.6 | 13.7 | 13.6 | 13.4 |

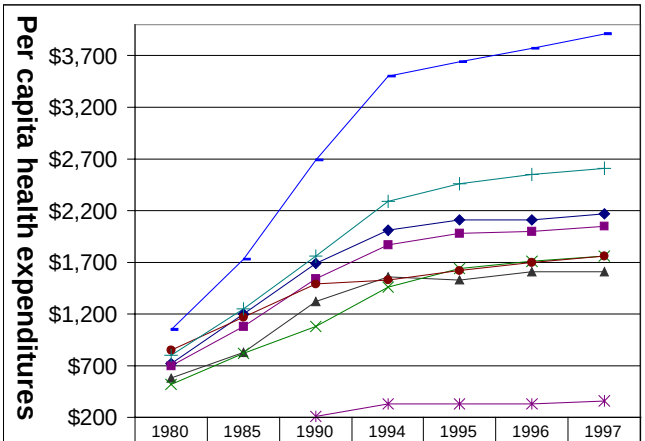
During 1980 Sweden dedicated a higher percentage of their GDP to health than any other country in the world, although, the United State had always the highest per capita expenditures. During the following years, Sweden lowered the percentage of the GDP for health care and recently has been almost stable at 8.6% until 1997. After 1980, the United States had the largest health expenditure expressed as a percentage of the GDP, with a rapid growth to 13.6% reached in 1994. Since 1995, this figure has been decreasing slightly.

Japan had a decrease from 1985 to 1990, but increased after that date to reach a stable value of around 7.2%. Italy instead had a fast rising in health care expenditure from 1985 to 1994 and a sharply decreasing one in 1995, to reach the value around 7.7% in the year. Canada shows a reduction after 1994. Switzerland's expenditures grew constantly to reach 10.1% of the GDP in 1996. Expenditures by the other countries listed in Table XVI also grew constantly in percentage of expenditures. The United States, however, has a much higher health care expenditure per capita (see Table XVII) than any other country (e.g., $3,912 compared to the average of $2,300 for other industrialized countries in 1997).

Following is the total health care expenditure as a percentage of GDP for some selected countries for the year 1996: U.S., 13.6%, Germany, 10.8%, Switzerland, 10.1%, France, 9.8%, Canada, 9.3%, Netherlands, 8.7%, Sweden and Australia, 8.6%, Greece, 8.4%, Iceland, 8.2%, Denmark, 8.1%, Austria, 8%, Portugal, 7.9%, Italy, Norway, and Finland, 7.8%, Spain, 7.4%, New Zealand, 7.3%, Japan, 7.1%, United Kingdom, 6.9%, Luxembourg, 6.8%, Hungary, 6.6%, Ireland, 6.4%, Korea, 5.9%, Poland, 4.9%, Mexico, 4.6, Turkey, 3.8%.

The detailed study of health care expenditures in United States is an example similar to that carried out for other countries in the past. In fact, several studies were made in the Netherlands, England, Germany, and Japan two decades ago when the CT[1] was first introduced. A few years later the advantages of larger, more technologically advanced devices such as CT and MRI devices contributed to improvement in health care and also a reduction in health care costs[26], although the CT and MRI units were more expensive than older technology in use at that time. For example, Japan, which has more CT scanners per million inhabitants[1], has a lower per-capita expenses and lower health care expenditure as a percentage of GDP than the U.S.

**TABLE XVII. PER CAPITA HEALTH CARE EXPENDITURES IN DIFFERENT COUNTRIES FROM 1980 TO 1997 (SOURCES[37]).**




| | 1980 | 1985 | 1990 | 1994 | 1995 | 1996 | 1997 |
|---|---|---|---|---|---|---|---|
| Canada | $716 | $1,201 | $1,695 | $2,006 | $2,106 | $2,112 | $2,175 |
| France | $701 | $1,082 | $1,539 | $1,869 | $1,984 | $2,005 | $2,047 |
| Italy | $579 | $830 | $1,321 | $1,562 | $1,534 | $1,615 | $1,613 |
| Japan | $524 | $820 | $1,082 | $1,463 | $1,637 | $1,713 | $1,760 |
| Mexico | | | $210 | $328 | $335 | $330 | $363 |
| Sweden | $850 | $1,172 | $1,492 | $1,533 | $1,623 | $1,701 | $1,762 |
| Switzerland | $801 | $1,250 | $1,760 | $2,294 | $2,464 | $2,548 | $2,611 |
| USA | $1,052 | $1,735 | $2,689 | $3,501 | $3,637 | $3,772 | $3,912 |

37 Sources: Schieber GJ, Poullier JP, and Greenwaid LG. U.S. health expenditures performance: An international comparison and data update. Health Care Financing Review vol 13 no 4. Washington: Health Care Financing Administration, September 1992; Anderson GF and Poullier GP. Health spending, access, and outcomes: Trends in industrialized countries. Health Affairs vol. 18 no 3, May/June 1999; Office of National Health Statistics, Office of the Actuary. National health expenditures, 1997. Health Care Financing Review vol. 20 no 1. HCFA pub no 03412. Washington: Health Care Financing Administration, March 1999; Organization for Economic Cooperation and Development Health Data File. Organization for Economic Cooperation and Development.

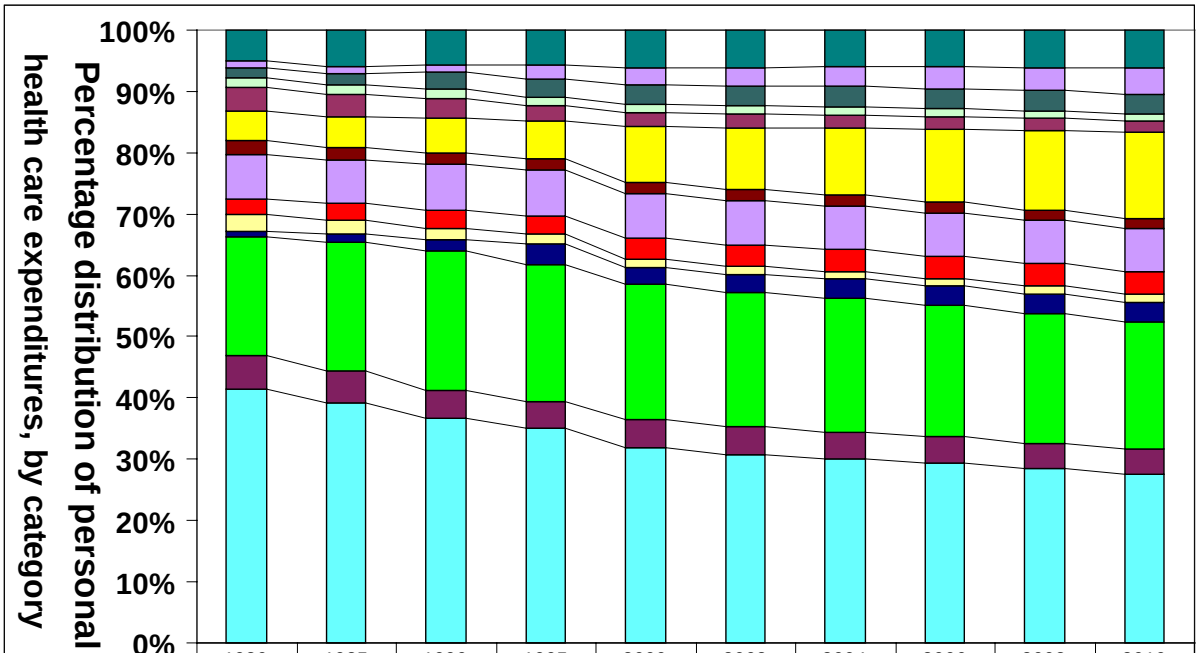
## Appendix A.2. Health care expenses in the U.S

Table XVIII shows the historical and projected data of the percentage distribution of personal health care expenditures in U.S. by type of service during the years 1980-2010 [11]. The historical data from 1990 to 2000 of Table XVIII must be compared with the projected data reported by HCFA in [13], [14], [15], [16], [17], [18], [19] during the previous years. During the previous years, HCFA overestimated the increase in overall health care cost for future years but grossly underestimated spending on pharmaceuticals.

The percentage of distribution for type of service is different for different countries. For example, in the United States many hospitals have closed during the past years and Table XVIII shows that this trend is expected to continue. This occurs although in other countries the percentage of the health care expenditure for hospitals is much higher than in the U.S., and it is well known that for a similar procedure the patient's stay in the hospital is much shorter in the U.S. than in hospitals of European countries. With the exception of the categories "constructions" and "research" which are considered investment, all other categories [9]. The figures showing sales of medical and irradiation equipment must be found from statistics from the U.S. Census Bureau [12].

It is important to note that the sharp increase in drug expenditures from 1995 to 2000 does not correspond to a greater decrease of the death rate for the same period in Table X. This might raise the question whether the increase in drug expenditures would be more cost-effective if the possibility existed to optimize their use by verifying their effect with a technologically advanced medical imaging instrument such as the 3D-CBS.

**TABLE XVIII. HISTORICAL DATA AND PROJECTED DATA OF THE PERCENT DISTRIBUTION OF PERSONAL HEALTH CARE EXPENDITURES IN U.S. DURING THE YEARS 1980-2010, BY TYPE OF SERVICE. (SOURCE: HCFA[17] [11]). SEE ALSO THE TOTAL HEALTH CARE EXPENSES IN TABLE II.**




| | 1980 | 1985 | 1990 | 1995 | 2000 | 2002 | 2004 | 2006 | 2008 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|
| Admin. | 4.9 | 5.8 | 5.6 | 5.7 | 6.1 | 6.1 | 6 | 6 | 6.1 | 6.2 |
| Other pers. | 1.3 | 1.2 | 1.3 | 2.3 | 2.8 | 2.9 | 3.1 | 3.4 | 3.7 | 4.1 |
| Other Profess. | 1.4 | 1.9 | 2.6 | 2.8 | 3.1 | 3.2 | 3.3 | 3.3 | 3.3 | 3.3 |
| Vision | 1.6 | 1.5 | 1.6 | 1.5 | 1.4 | 1.4 | 1.3 | 1.3 | 1.2 | 1.2 |
| Other Med. Prod. | 3.9 | 3.6 | 3.1 | 2.4 | 2.3 | 2.3 | 2.1 | 2 | 1.9 | 1.8 |
| Drugs | 4.9 | 5.1 | 5.7 | 6.1 | 8.9 | 10 | 11 | 11.9 | 12.9 | 13.8 |
| Research | 2.2 | 1.9 | 1.8 | 1.7 | 1.8 | 1.8 | 1.7 | 1.7 | 1.7 | 1.7 |
| Nursing care | 7.1 | 7.1 | 7.5 | 7.5 | 7.3 | 7.2 | 7.1 | 7 | 7 | 6.9 |
| Public | 2.7 | 2.7 | 2.9 | 3.1 | 3.3 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 |
| Construction | 2.7 | 2.2 | 1.9 | 1.5 | 1.4 | 1.3 | 1.3 | 1.3 | 1.3 | 1.2 |
| Home Hlth care | 0.9 | 1.3 | 1.8 | 3.3 | 2.7 | 3 | 3.1 | 3.2 | 3.2 | 3.2 |
| Physician | 19.1 | 21 | 22.6 | 22.2 | 22 | 21.8 | 21.7 | 21.3 | 21 | 20.6 |
| Dental | 5.4 | 5 | 4.5 | 4.4 | 4.5 | 4.5 | 4.4 | 4.3 | 4.2 | 4.1 |
| Hospital | 41.3 | 39 | 36.5 | 34.7 | 31.7 | 30.6 | 29.8 | 29.1 | 28.2 | 27.3 |

Figure 17 shows the percentage distribution for the selected years 1980, 1999, and 2010 of U.S National Expenditures (NHE) by type of service as defined by HCFA on http://www.hcfa.gov/stats/nhe-oact/lessons/ (The group "drugs" is limited to spending for prescription drugs purchased from retail outlets. The value of drugs and other products provided to the patient by hospitals (on inpatient or outpatient basis) and nursing homes and by health care practitioners as part of a provider contact are implicit in estimates of spending for those providers' services. (Source: [11]).

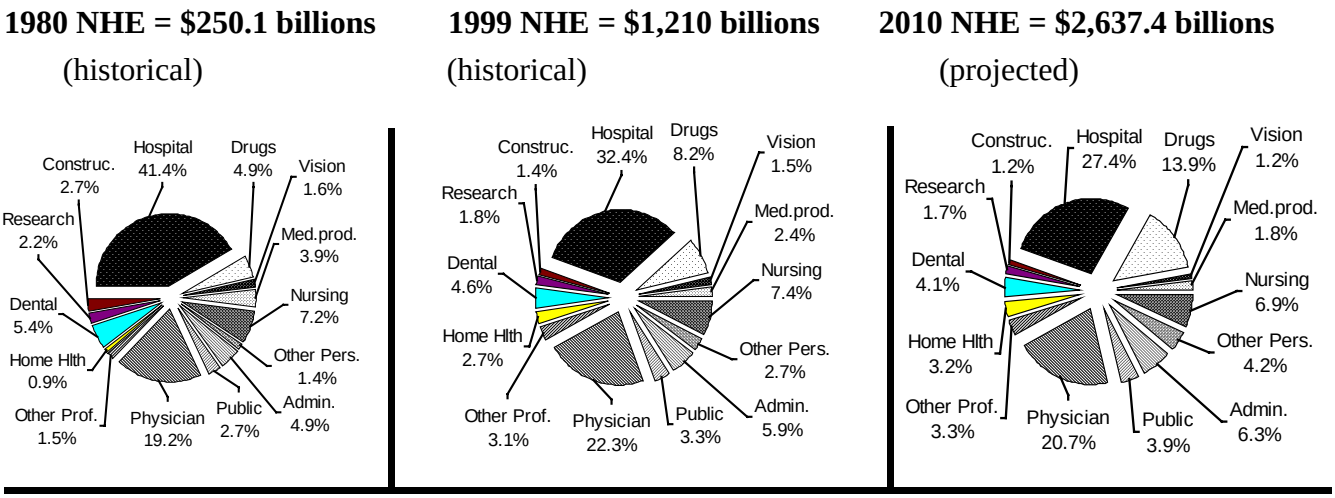



**Figure 17. Percent distribution of health care expenditures, by type of service: United States, selected years 1980, 1999, and 2010. (Source: [11], [13])**

Figure 18 shows the percentage distribution of health care expenditures by type of service in the U.S. during the selected years 1980, 1999, and 2010 when all expenses of the category "prescription drugs" in the U.S. are consolidated in one single category. (Source: IMS health [10]). Historical data for electromedical and irradiation instrumentation were obtained from the U.S. Census Bureau; projected data for 2000-2010 were based on the growth of the previous decade in the same category.).

It is clear from Figure 18 that the electromedical and irradiation instrumentation, with a percentage of around 1% of total health care costs, cannot be the cause of the increase in these total costs, while it is also clear that the trend in the U.S. is towards expense for drugs to reach that for hospitals.

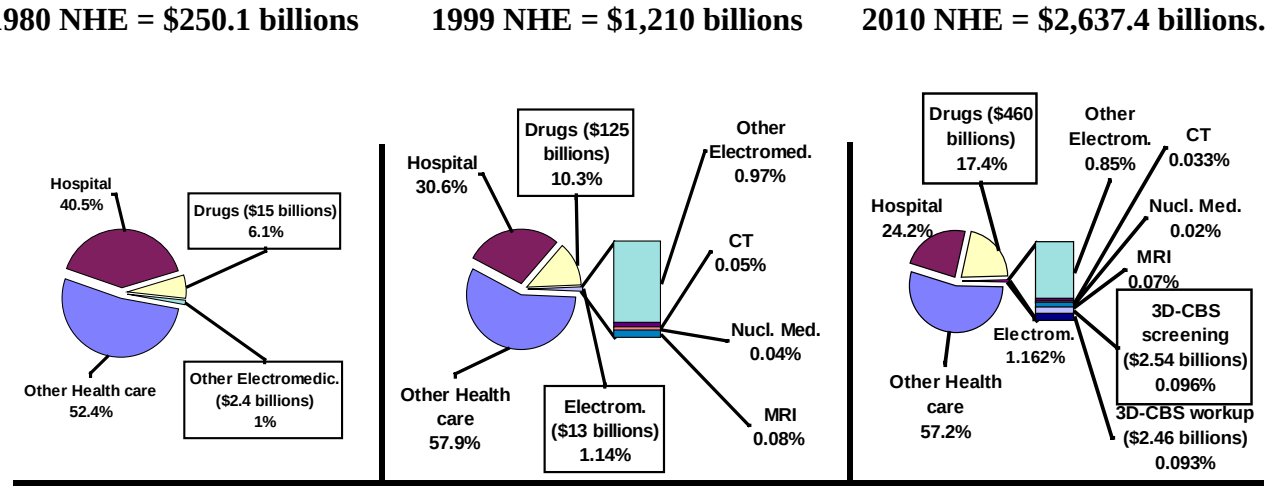



**Figure 18. Consolidation of all "drugs" expenses in one single category (Source: IMS Health [10], [12].**

(Notice how the expense for hospitals is reduced while the expense for drugs, projected in 1992 by HCFA [13] to be 5.8% by 2000 and 5.5% by 2010, increased instead to 10% in 1999 and is now projected to increase to 17.4% by 2010.)

# APPENDIX B. ADDITIONAL INFORMATION ON VERIFICATION OF THE TECHNOLOGY

Design Real-Time is an integrated high-level design environment for the development, verification, and implementation of scalable high-speed real-time applications for which commercially available processors fail because of throughput requirements.

The Design Real-Time software tools allow the user to design fast programmable real-time 3D-Flow systems [21], [23] with different sizes, topologies, and performance (8-bit, or 16-bit wide internal buses). The steps are: a) to create a system and simulate it in software, b) using the Electronic Design Automation (EDA) tools, to create a component in hardware, simulate, and verify each feature against the requirements of each section of the software system (e.g. stack, pyramid, real-time monitoring).

Design Real-Time:

- Interfaces with third-party EDA tools;
- Is based on a single type of replicated component, the 3D-Flow (PE in the form of an IP block);
- Is technology independent because the PE, IP block can be targeted to the latest technology;
- Takes the user to a higher level of abstraction and productivity gain during the design phase because of the simplicity of the 3D-Flow architecture, and the powerful tools, the set of predefined macros and the real-time algorithms available to the user;
- Allows for implementation of the user's conceptual idea into the fastest programmable system at the gate level.

## Appendix B.1. 3D-Flow Design Real-Time tools

1. Create a new 3D-Flow application (called project) by varying system size, throughput, filtering algorithm, and routing algorithm, and by selecting the processor speed, lookup tables, number of input and output bits for each set of data received for each algorithm execution;
2. Simulate a specified parallel-processing system for a given algorithm on different sets of data. The flow of the data can be easily monitored and traced in any single processor of the system and in any stage of the process;
3. Monitor a 3D-Flow system in real-time via the RS232 interface, whether the system at the other end of the RS232 cable is real or virtual; and
4. Create a 3D-Flow chip accommodating several 3D-Flow processors by means of interfacing to the EDA tools.

A flow diagram guides the user through the above four phases. A system summary displays the information for a 3D-Flow system created by the Design Real-Time tools.

## Appendix B.2. Interrelation between the entities in the Real-Time Design Process

Figure 19 is separated into two sections. On the left is shown the flow of the software design and simulation process to create and simulate a 3D-Flow system, on the right is shown the System-On-a-Chip for High-speed Real-time Applications and TESting (SOC-HRATES) hardware design process. The center of the figure shows the common entities of the system:

1. The IP 3D-Flow processing element as the basic circuit to which has been constrained the functionality required by different applications;
2. A set of 3D-Flow real-time algorithms and macros organized into a library;
3. The System Monitor software package that allows the user to monitor each 3D-Flow processor of the 3D-Flow system (hardware or VPS –Virtual Processing System--), via RS-232 lines. The System Monitor (SM):
   a) Performs the function of a system-supervising host that loads different real-time algorithms into each processor during the initialization phase;
   b) Detects malfunctioning components during run-time. (A sample of data is captured at the processor speed of 80 MHz at a preset trigger time for 8 consecutive cycles (called snap-shot), and is transferred at low speed (at the RS-232 speed of 230 KBaud) to the System Monitor for debugging and/or monitoring);
   c) Excludes malfunctioning processors with software repair by downloading into all neighbors a modified version of the standard algorithm, instructing them to ignore the offending processor.

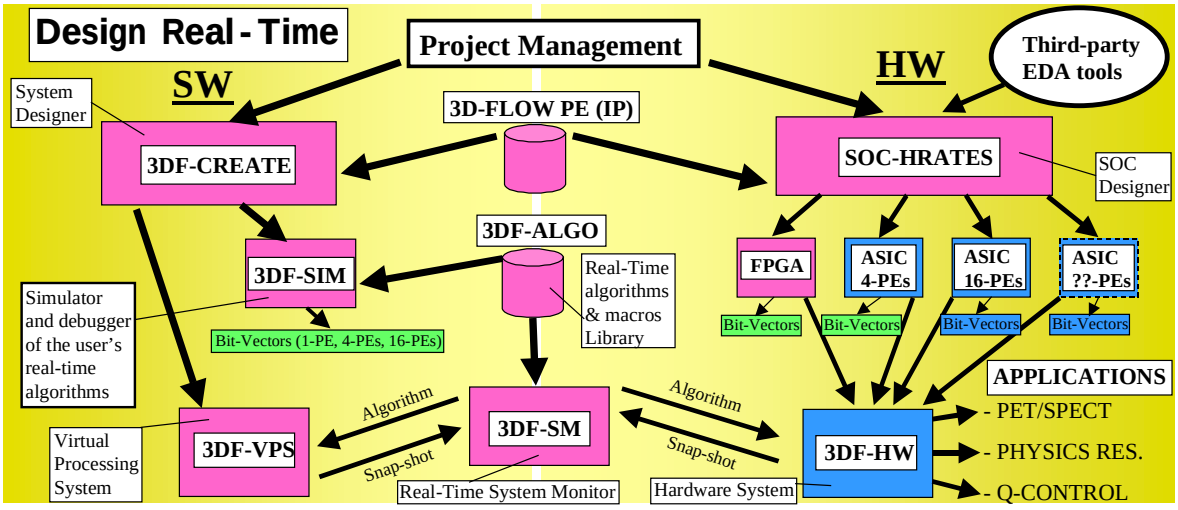



**Figure 19. Interrelation between entities in the Real-Time Design Process.**

The "3DF-CREATE" software module allows the user to:

1. Define a 3D-Flow system of any size;
2. Interconnect processors for building a specific topology with or without the channel reduction stage ("pyramid");
3. Modify an existing algorithm or create a new one. The complexity of the real-time algorithms for identifying particles arriving from multiple channels at high rate at the input of the 3D-Flow system, such as the ones reported in [25], [21], [45], [46], have been examined and fewer than 10 layers (corresponding to 20 steps, each executing up to 26 operations) of 3D-Flow processors are required;
4. Create input data files to be used to test the system during the debugging and verification phase.

The "3DF-SIM" module allows for simulation and debugging of the user's system real-time algorithm and generates the "Bit-Vectors" to be compared later with the ones generated by the third-party silicon foundry tools.

The "3DF-VPS" module is the Virtual Processing System that emulates a 3D-Flow hardware system.

The right side of Figure 19 shows the flow of the hardware implementation of the 3D-Flow system in a System-On-a-Chip (SOC). The same common entity, the IP 3D-Flow processing element (PE), shown in the center of the figure and previously used as the behavioral model in the simulation, is now synthesized in a specific technology by using the same code.

The number of chips required for an application can be reduced by fitting several PE's into a single die. Each PE requires about 100K gates and the gate density increases continually. Small 3D-Flow systems may fit into a chip. For this reason, it is also called SOC 3D-Flow. However, when an application requires the building of a 3D-Flow system that cannot be accommodated into a single chip, several chips each accommodating several 3D-Flow PEs can be interfaced with glueless logic to build a system of any size to be accommodated on a board, on a crate, or on several crates [21].

### Appendix B.3. Design Real-Time verification process

The verification process of an entire 3D-Flow system can be performed down to the gate-level in the following steps:

- The 3DF-SIM: a) extracts from the system the input data for the selected 3D-Flow processor(s) for which an equivalent hardware chip (which was targeted to a specific technology) has been created, and b) generates the Bit-Vectors for the selected processor(s);
- The same input data and the same real-time algorithm are applied to the hardware 3D-Flow model, and the simulation is performed using the third-party tools;
- Bit-Vectors generated by the third-party tools using the hardware model are compared with the Bit-Vectors obtained by the previous software simulation (3DF-SIM);
- Discrepancies are eliminated.

### Appendix B.4. Results from the use of Design Real-Time

The use of the Design Real-Time tools has made it possible to determine the parameters that led to design the data acquisition and processing system for pattern-recognition (particles in HEP experiments) described in [21] and [24], providing:

1. Simulation and implementation results of a real-time system for the Level-0 trigger of LHCb [21], [2] experiment at the Large Hadron Collider at CERN [47] (which are described in the following sections of this article); and
2. The simulation and verification of the LHCb HEP Level-0 system trigger algorithm simulated using 3DF-SIM vs. the results (test pattern in the form of bit-vectors) obtained from the EDA tools from the design of
   a) a single 8-bit wide internal bus 3D-Flow PE version synthesized for different FPGAs,
   b) a 3D-Flow ASIC chip containing four PEs with 16-bit wide buses synthesized into a 0.5 μm technology, and
   c) the same four PEs into a 0.35 μm ASIC technology.

   Simulation has been performed, and Bit-Vectors have been compared between the system simulator (3DF-SIM) and a 3D-Flow chip implemented with 0.35 μm Cell Based Array (CBA) technology at 3.3 Volts. The CBA ASIC EDA design tools show dissipation of 884 mW @ 60 MHz and a die size of 63.75 $mm^2$ for a chip with 4 3D-Flow processors.

Implementation with the current technology of 0.18 μm which has a gate count of ~65K gates per $mm^2$ requires about 1.5 $mm^2$ of silicon per PE. A chip accommodating 16 PEs dissipates 23 nW Gate/MHz, and requires a silicon area of about 25 $mm^2$ in 0.18 μm technology (leading to a chip @ 1.8 Volts, 676-pin EBGA, 2.7 cm x 2.7 cm).

## APPENDIX C. DEFICIENCIES OF CURRENT PET MACHINES AND THEIR REMEDIES

Although the CT images are of good quality at the expenses of a relatively high x-ray beam (which should be lowered in order to lower the risk to the patient), the PET images are of poor quality because only a few emitted photons from the patient's body are captured by the PET detector. Other deficiencies of the current PET machines are: low coverage of the entire body, false positives, high radiation dose, slow scanning, high examination costs. The increased efficiency of the 3D-CBS in capturing photons, will provide improvements in both: lowering the radiation dosage for CT scan and improve the PET image quality (in addition to also lowering the PET radiation dosage).

### Appendix C.1. Limiting factors of current PET.

Briefly, following is a list of the main areas of inefficiencies in the current PET which prevent maximum exploitation of positron emission technology.

1. The image quality of current PET is poor because it has:
   a) a short FOV, limited by a non efficient electronics that does not offset the cost of the detector if the FOV were increased (see also next section about false positive and false negatives);
   b) no accurate time-stamp assigned to each photon (a) limiting the detection of neighboring photons emitted within a short time interval, (b) causing long dead-time

of the electronics and (c) increasing randoms[38], (most PETs do not have any photon time-stamp assignment);

c) analog signal processing on the front-end electronics limiting photon identification because of poor extraction of the characteristics of the incident photon and absence of the capability to improve signal-to-noise (S/N) ratio;

d) detector boundary limitations to 2x2 PMT blocks, no correlation between signals from neighboring detector blocks, no full energy reconstruction of the photons that hit the detector, (most of current PET do not attempt to make any energy reconstruction of the event, but take decisions in accepting or rejecting first a photon and later an event based on the threshold of a single signal).

e) dead-time of the electronics. Dead-time of the electronics is due to any bottleneck (e.g., multiplexing of data from many lines to a single line, saturation on input, processing, saturation on output) present at any stage of the electronics.;

f) saturation of the electronics at the input stage due to its inability to detect and process two nearby photons that hit the detector within a short time interval;

g) costly and inefficient coincidence detection circuit (most current PET [31], [29] have a coincidence detection circuit that tests for coincidence all possible combinations of the Lines of Response (LOR) passing through the patient's body). Although current PET have made a compromise in coincidence detection efficiency versus circuit complexity, by using a coarse segmentation of the detector in order to reduce the number of LOR to be tested for coincidence, that approach is however an impediment to increasing the FOV (See more details in Section 14.7.2 of [1] and Section 6.3 of [25]). This approach adds unnecessary complexity to the electronics of the current PET and makes it unreasonably costly to build a circuit with an acceptable efficiency when more detector elements are added to the detector (which is required in extending the FOV);

h) saturation of the electronics at the output stage due to the limiting architecture of the coincidence detection circuit (See Section 14.7.2.4 of [1]);

i) a high number of "Randoms" due to the non accurate measurement of the photon arrival time and to the long (about 12 ns) time window used when determining if two photons belong to the same event;

j) poor measurement of the attenuation of different tissues at different locations in a patient's body. These measurements are necessary for calculating the attenuation correction coefficients for PET scan;

2. The false positives and false negatives shown in images from current PET, are a consequence of all of the above not having: (a) a DSP (see Section 7.2) on each electronic channel, with neighboring signal correlation capabilities, which extracts with zero dead time, the full characteristics of the incident photon and improves the S/N ratio of the each signal before adding it to other signals, (b) good attenuation correction coefficients, (c) a good, efficient, and simple coincidence detection circuit, and (d) a sufficiently long FOV (which prevent capturing most photons as shown on the left side of Figure 1 and Figure 13) that are the impediments in obtaining good quality images;

3. The high radiation dose delivered to the patient is required by the current PET because each examination needs more than 20 million photons in coincidence (or a number that provides a sufficient statistic to build an image). The short FOV and the inefficient electronics and allows accumulation of fewer than 2 photons in coincidence for every 10,000 emitted. This inefficiency requires to one administer a necessarily high radiation dosage to the patient in order to keep the examination time within an hour.

4. The slow scanning time is because of the short FOV of the current PET and of the low efficiency of the electronics. The limited efficiency mentioned above of 2 out of 10,000 requires long acquisition time. Examinations longer than one hour are unacceptable because (a) the biological process desired to observe and the radioisotope decay activity would be over, (b) the patient would be uncomfortable, and (c) the cost would be even higher that what it already is;

5. The current high cost of the examination is due to:

   a) the high cost of the huge dose of radioisotope required;

   b) the slow scanning time that allows only six to seven patients per day to be examined; and

   c) the cost of highly paid personnel who must operate the slow machine.

## Appendix C.2. Distinctive innovative features of the 3D-CBS

The technological innovations of the 3D-CBS design are the following:

1. ***Accurate time determination of the arrival of the incident photon to the detector and "time-stamp" assignment to the detected photon.*** The front-end circuit of the 3D-CBS accurately determines, by means of a Constant Fraction Discriminator (CFD), a Time-to-Digital converter (TDC), further improved with the DSP real-time algorithm and assigns of the time-stamp to each event. (See also Sections 13.4.4 and 13.4.10 of [1])
2. ***Digital processing of the front-end electronics versus analog processing.*** With the advent of fast analog-to-digital converters and new processors oriented toward digital signal processing (DSP), there arose the tendency to treat analog signals in digital form, thus using discrete algorithms instead of analog functions [48]. The advantages of the digital versus analog processing are

[38] Randoms are photons in time coincidence belonging to two different events.

principally perfect stability (no drift due to temperature or aging), repeatability (not dependent on component tolerance) easy design (programming an algorithm), lower cost of programming the same devices for different functions, absence of the need for component calibration while system calibration can be performed easily by reading parameters acquired during a calibration procedure, accuracy limited only by converter resolutions and processor arithmetic precision, low power consumption, testability, and high circuit density. **In contrast, upper speed limits of DSP using the standard DSP architecture are inferior to those of analog processing. This is the reason why many applications are still using analog processing.** The manufactures of current PET are among those still using analog processing as is described in detail in Section 14.7.1.1 of [1], or as can be found directly from the manufacturers documentation in [30]. However, this barrier has been overcome with the 3D-Flow sequentially-implemented parallel architecture described in Section 4. With the 3D-Flow architecture using a clock of only 80 MHz (or at a speed that can be implemented with a low cost CMOS technology), it is now possible to have all the DSP advantages listed above in addition to special instructions for particles identification, while sustaining a high data input rate.

3. ***Elimination of the saturation at the input stage for any detector type and speed and for any simple or complex real-time algorithm***. The implementation that satisfies the requirements of eliminating saturation at the input stage is the use, for each electronic channel, for a number of cascaded 3D-Flow processors as shown in Figure 9 which is proportional to the processor speed, the number of steps of the algorithm to be executed, and the data input rate. For example: sampling a PET detector at 20 MHz (see details in reference [21], and Section 13.4.3 of [1]) with a 3D-Flow processor running at 80 MHz that requires the execution of a real-time algorithm of less than 20 steps, needs a 3D-Flow system of 5 layers[39]. Although the entire PET electronic system can receive a data packet every 50 ns, each layer can executes an algorithm lasting up to 20 x 12.5 ns = 250 ns, thus each layer takes one data packet from the detector and skips 4 sets of data packets that will be forwarded to the other processors, **via the bypass switches**, that are located in the other four layers (see Figure 9). If the sampling rate of the detector increases or if the algorithm becomes more complex, one or more layers of 3D-Flow processors is added in order to reach a situation where the system will never saturate.

4. ***The implementation of a new concept that all signals within a defined view angle of the detector from the emitting source at the center of the detector are processed and correlated digitally***. A programmable algorithm (see next section and references [1], [21], [25]) is executed in real-time on all signals received from a defined view angle, together with the signals of the neighboring detector elements in order to extract, directly from the raw data, all information of the interaction between the photon and the detector. In current PET, the approach is of extracting from a few signals one type of information, from other set of signals other information, and so on. The next level of the electronics combines the results of the first level of the processing of partial data. The reason for using that approach which provides less accuracy in the calculation of the parameters characterizing the incident photons, was because **the electronics on current PET can handle only few operations on a few data at a high rate.** The 3D-Flow architecture, on the other hand, can handle more data, performing complex real-time algorithms on them while receiving at high data input rate because of the sequentially-implemented parallel architecture described in the next section. The combination of the detector raw data received within a defined view angle is performed in a FPGA circuit (from PMT, photodiodes, time-to-digital converter, etc.) [24]. These data are then sent to the 3D-Flow processor in a formatted word of 32- or 64-bit (See reference [21], and Section 13.4.3 of [1]).

5. ***The 3D-Flow sequentially-implemented parallel architecture (see*** Table III ***and*** Figure 9***) allows execution of complex, programmable real-time algorithms*** which include correlation with neighboring signals, and fully reconstruct the energy, extract the information of the type of interaction between the photons and the crystal, improve the signal–to-noise ratio, measure accurately the depth of interaction, resolve photon pileup, and capture most of them (See example of the real-time algorithm for photon identification on Sections 13.4.11.2, and 13.4.11.3 of [1]). **Thus this architecture improves image quality, and leads to lower radiation dosage and to shorter scanning time.** The concept of the 3D-Flow architecture is described in simple terms in [49], while a more complete description of the concepts, implementation and application can be found in [1], [2], [3], [21], [23], [24], [25], and [26]. **One of the differences is that in the standard pipeline a data moves at each clock from one stage to the next, while in the 3D-Flow system a data remains in the same stage for several clocks, until the entire algorithm is completed**. The basic 3D-Flow component has been implemented in a technology-independent form and synthesized in 0.5 μm, 0.35 μm technology, and in FPGA's Xilinx, Altera and ORCA (Lucent Technologies). A cost-effective solution is to build the 3D-Flow in 0.18 μm CMOS technology @ 1.8 Volts, accommodating 16 3D-Flow processors with a die size of approximately 25 $mm^{2,}$ and a power dissipation [gate/MHz] of 23 nW. Each 3D-Flow processor has approximately 100K gates, giving a total of approximately 1.7 million gates per chip. (See [1], [23], [26], [25] for more details). Among the features of the 3D-Flow architecture, the following are listed as are pertinent to advantages which suite this project:

[39] A layer is an array of 3D-Flow processors equivalent to the number of channels of the PET detector, where each processor is interconnected to its four neighbors through North, East, West and South ports.

- Eliminates saturation on the input data, no deadtime, no bandwidth limitation (see Appendix C.1 item 1.e and Appendix C.2 item 3)
- Allows execution of programmable, simple or complex real-time algorithms with an execution time of an uninterruptable sequence of operations which is longer than the time interval between two consecutive input data. The same 3D-Flow system can be used for different crystal detectors (slow and fast) and can be adapted to an optimal extraction of the information of the interaction of incident photon with the crystal detector by simply loading a different real-time pattern recognition algorithm in the 3D-Flow program memory
- Eliminates the boundaries with a convenient way to communicate with the neighbors (3x3, 4x4, 5x5, etc.) through North East, West, and South ports.
- The 3D-Flow instruction set includes all typical DSP operations such as multiply-accumulate, arithmetic and logic operations, and in addition has operations to move data to/from the 10 input output ports and operations comparing the received data with the 8 or 24 neighbors in a single cycle (to check for local maxima). Up to 26 operations in different units (2 ALUs, 1 MAC/Divide, 64 registers, 5 input FIFOs, 32 comparators, 1 timer, 4 data memories, all connected via four internal busses) can be executed in a single cycle. This balance of operations of moving and computing data allow for the execution of all typical DSP filtering techniques, for signal-to-noise ratio improvement and algorithms for photon identification (see Section 13.4.11 of [1]), all essential to improve PET efficiency. Among the operations performed are also those of digital signal-processing operations on the incoming bit string such as: (a) variable digital integration time (or pile-up identification/correction), which allows for the maximum count rate capabilities while preserving spatial resolution; (b) depth of interaction, which reduces the parallax error by performing calculations based on pulse shape discrimination (PSD), and/or pulse height discrimination (PHD); (c) local maxima, to avoid double counting, (d) centroid calculations to improve spatial resolution or/and techniques of most likely position given the statistical nature of the signals; (e) correlation with neighboring signals; and (f) improving the timing resolution from the information received from the time-to-digital converter (TDC) and pulse shape analysis.

6. ***A simplified coincidence detection circuit***. In the new design described in [1], only the detector elements (coupled to a PMT or APD), that are hit by a photon which was validated by a thorough real-time, front-end pattern recognition algorithm, are then checked for coincidence. **This method is much simpler than the one used in the current PET, which compares all of the possible LOR** (see references [31], [29] or Section 13.4.14 of [1] for more details). The number of comparisons for finding the coincidences in the 3D-CBS is proportional to the radiation activity (e.g., for about 80 million hits per second into the detector, corresponding to a limit of the radiation dose to the patient, only 120 million comparisons per second are necessary) and not to the number of detector elements as in the current PET (See Section 4 of this document and Section 14.7.2 on page 148 of [1] for the implementation of the coincidence circuit with the 3D-Flow and the flow chart of the programs). In the new design, the coincidence detection problem is solved with simple electronic circuit that funnels all hits detected to a single electronic channel, sorts the events in the original sequence, as shown in Figure 13-22 of [1], and compares all hits within a given time interval, for validation of time-stamp and location situated along an LOR passing through the patient's body. (See Section 13.4.14.1 on page 123 of [1]).
7. ***Elimination of the saturation at the output***. The elimination of the saturation at the output stage is easily achievable by implementing a circuit that performs the number of comparisons corresponding to the highest radiation activity that a detector should ever receive. Assuming to have at most four hits at the detector during one sampling of 50 ns, (corresponding to a rate of 80 million single photons per second hitting the detector), than because we can have at most 6 comparisons out of four data, the total number of comparison to avoid saturation will be $120 \times 10^6$ comparisons per second. (See section 13.4.14 of [1] for more details).
8. ***The new electronic design now makes the extension of the PET FOV cost-effective***. One of the most important benefits of the use of the innovations set forth in this article is that of efficiently capturing more photons. This moves beyond the point where the current PET manufacturers erroneously thought that **the benefits of capturing more photons and decreasing the examination time could not offset the significant increases in the costs associated with PETs with a longer FOV.** In addition, these innovations allow to reduce the radiation dose to the patient permitting examination annually on asymptomatic people. The use of the 3D-Flow architecture described in Section 4 and the funneling circuit of the coincidence detection section described previously, allows one to extend the FOV of the PET to any length and to any number of detector elements.
9. ***The incorporation of the Electron Beam Computed Tomograph (EBCT) and Positron Emission Tomograph (PET) in a single apparatus with a single detector,*** eliminating completely the motion artifact in the image is facilitated by the use of the 3D-Flow DSP that can efficiently execute the calculations for identifying and separating from the same crystal detector the two types of incident photons (CT X-rays and PET $\gamma$ rays).
10. ***The accurate measurement of the attenuation during CT x-ray transmission*** scanning will be used to calculate a more accurate attenuation correction coefficient for the PET examination.

Other innovations that provide benefits to the 3D-CBS machine are: hardware, software, cabling, system architecture,

component architecture, detector element layout, data acquisition and processing, and detection of coincidences.

## Appendix C.3. Limitations of current PET remedied by 3D-CBS

In order to reconstruct an image of the metabolism of the cells of the patient's body, it is necessary to capture more than 20 million photons in coincidence emitted by the radioactive source within the patient's body during each examination. If the electronics is not rigorous in selecting the "good[21]" photons, the image quality will be poor and the machine will require additional scanning time. This presents the disadvantages that (a) a particular biological process might be finished by the time the scan has accumulated more than 20 million photons; and (b) the "bad" photons acquired along with the "good" ones cannot be subtracted during off-line filtering algorithms without subtracting several good photons along with them.

The current PET imaging machines do not thoroughly analyze in real-time the data received from the detector which contains the information of the characteristics of the interaction between the incident photon and the crystal. The result is that many "good[21]" photons are missed and photons are captured that later in the process must be disregarded as "bad" photons. This fails to provide a clear image to help the physician to recognize subtle differences in normal anatomies. The innovations set forth in this article remedies the above in the following manner:

### The remedies offered by the 3D-CBS to the above deficiencies

1. The image quality of current PET is improved with the following (see the same items listed as a problem in Appendix C.1):
   a) a FOV longer than one meter, covering almost the entire size of the patient's body. The simpler, lower cost, more efficient electronics described in this article and in references [1], [2], [3], [21], [23], [24], [25], [26] allows to capture more "good" photons providing the benefit of improving the image quality, decreasing the radiation dose to the patient and shortening the examination time which compensates the higher cost of the detector of a PET with a longer FOV;
   b) accurate photon arrival time determination and assignment to the input data packet using the circuit described in Appendix C.1, item 1 of this article and in Sections 13.4.4 and 13.4.10 of [1]. The determination of the accurate arrival time of the photon at the detector allows to better identify "good" events by the coincidence detection circuit;
   c) digital signal processing on the front-end electronics at each electronic channel with neighboring signal correlation as described in Appendix C.1, item 2 of this article and in reference [2]. Using digital signal processing techniques, one can most efficiently extract the characteristics of the interaction between the incident photon and the crystal detector and improve the signal-to-noise ratio on each signal before adding them with other signals;
   d) ***elimination of detector boundaries by means of the North, East, West, and South communication ports*** of the 3D-Flow architecture as described in Appendix C.1, item 5 of this article and in Section 13.4.8 of [1]. The possibility to exchange information, to/from neighboring detectors, in real-time during acquisition, allows to for the complete reconstruction of the energy of the emitted photon which permits a better selection and classification of them;
   e) ***elimination of dead-time in the electronics***. The analysis of bottlenecks on the electronics of current PET and the design of a dead-time free system with the 3D-Flow architecture is described in detail in Section 13 and 14 of [1];
   f) , elimination of the saturation of the electronics at the input stage. The bypass switches of the 3D-Flow architecture (see Table III and references [2], [21]) allow the electronics of the 3D-CBS to sustain, with zero dead time, a data input rate of 20 million events per second at each channel. (This is equivalent to a total system input bandwidth for 1,792 channels or about 35 billion events per second compared to the 10 million events per second offered by the current PET.) This capability **eliminates electronic saturation when any type of (fast or slow) detector is used.** Electronics saturation, which is one cause of inefficiency of the current PET, should not be confused with detector saturation of the slow crystals. For example, considering a BGO crystal with a decay time of about 300 ns and an over all recovery time of about 700 ns, one could conservatively consider that the crystal will saturate at about 1 MHz. Because detectors are made of many crystals cut in 2 mm x 2 mm, or 4 mm x 4 mm, only a small portion where the photon hits the detector and a few surrounding detector elements could be affected by crystal saturation if another photon should arrive during the same time interval of 1 μsec. However, the 3D-CBS electronics has the capability of detecting any other photon arriving in any other part of the detector during the same time, up to one every 50 ns (higher than 1 μsec in order to cope with fast crystals) at the same location, with a time difference resolution between two different detected photons of 500 ps (the 500 ps resolution of the electronics which is provided by the resolution of the Time-to-Digital converter in some cases may be higher than the time resolution of slow crystals. See Section 13.4.10 of [1]);
   g) ***a simplified coincidence detection circuit sensitive to the radiation activity rather than to a number of detector elements*** (see Appendix C.1, item 6) captures more photons in coincidence more efficiently at a lower cost, improves image quality, allows lower radiation dosage, and leads to shorter scanning time. The coincidence circuit of the 3D-CBS is comparing only the signals of the detector elements that received a photon instead of comparing signals from all possible connection (LOR) of detector elements with an LOR

passing through the patient's body, as it is implemented in current PET [31];

h) ***elimination of the saturation at the output***. Using the 3D-Flow coincidence detection approach, the elimination of the saturation at the output stage is relatively simple because after having set the maximum radiation dose that will ever hit the detector, it is sufficient to implement the circuit(s) that performs the number of comparisons necessary to detect the maximum number of expected photons in coincidence (See Appendix C.2, item 7 of this article and Section 14.7.2.4 of [1]). This number, will always be lower and simpler than the coincidence detection circuit used in the current PET, which performs about 3 billion comparisons per second in seven ASICs. The circuit would be simpler because 3 billion comparisons per second corresponds to an isotope dose to the patient higher than 100 mCi, which will not be administered because is too dangerous for a patient;

i) ***reduction of the number of "randoms[38]"*** by means of the accurate determination of the arrival time of the incident photon hitting the detector. The accurate calculation (by means of a CFD, TDC and/or further improved with DSP real-time algorithm. See Appendix C.1 item 1.b of this article and Section 13.4.10 of [1]) and the assignment of the time-stamp to each event allows for the use of a shorter time interval between two detected photons when determining if they belong to the same event. Reducing randoms improves image quality, lowers radiation dosage and shorten scanning time;

j) ***a very accurate calculation of the attenuation correction coefficients*** needed for PET image enhancement, using the information acquired during CT transmission scan. (See Section III of [2]);

2. Reduction of the false positives and false negatives because of the improvements described above and in Appendix C.2 and Section 7.3 in capturing more "good" photons and eliminating the "bad" photons at the front-end electronics during real-time processing. The main reasons that allow for acquiring better images which would allow the physician to recognize subtle differences in normal anatomies are: (a) the presence of a 3D-Flow DSP on each electronic channel, with neighboring signal correlation capabilities (see Figure 11and Figure 12), which extracts with zero dead time, the full characteristics of the incident photon and improves the S/N ratio on each signal before adding it to other signals, (b) good attenuation correction coefficients, (c) good, efficient, and simple coincidence detection circuit (see Appendix C.2 item 6), and (d) having a sufficiently long FOV which allow for capturing most photons as shown in Figure 1 and Figure 13.
3. Reduction of the radiation dose delivered to the patient to a negligible level (1/30 the radiation administered during current PET examination) that will permit annual screening and will permit several examination during the treatment of the disease with no hazard to the patient, allowing better monitoring it. This is possible because the 3D-Flow sequentially-implemented parallel architecture described in Appendix C.2 item 5 of this articles and in Section 13, 14 and 15 of [1] and in references [2], [3], [21] allow for the detection at a high data input rate, about 1,000 photons every 10,000 emitted, and capturing more than 20 million "good" photons in coincidence per examination in a short time. Figure 13 shows the factors contributing to increase the delivery of a higher radiation dose to the patient when current PET are used (Although the text is hard to read in the figure, the symbols in the picture show clearly to an expert in the field the difference between the old and the new approach. See more details on Section 14 of [1]
4. The fast scanning time of the 3D-CBS is possible because of the long FOV of its detector and of the highly efficient electronics. The high efficiency mentioned before of 1,000 out of 10,000 reduces acquisition to a short time. This allow the examinations be performed in 15 to 20 minutes with 3 to 4 minutes scan time (a) facilitating the capture of a specific biological process one desire to observe, (b) without making the patient uncomfortable, and (c) at a cost that would be greatly reduced from the current one;

4. The factors that will reduce the cost are:
   a. the lower cost of the negligible dose of radioisotope required;
   b. the fast scanning time that allows for the examination of 40 to 50 patients per day; and
   c. the cost of highly paid personnel who must operate the slow machine will be allocated over a larger number of examinations per day instead of only 6 to 7 patients/day.

Figure 2 shows how the 3D-CBS can acquire over 20 million photons in a shorter time compared to the current PET. This is equivalent to scan more patients per hour, thus it lowers the examination cost.

## List of the innovations which provide additional improvements to medical imaging technology

1. ***A single detector assembly for PET and CT, covering most of the patient's body (current PET/CT use two detectors, one for each modality with a moving bed on which the patient goes through both).*** In addition to completely eliminating picture blurring, this feature improves the imaging capabilities allowing the superimposition of anatomical pictures with functional imaging, provides very accurate attenuation correction coefficients, and utilizes the synergy of the other innovations to decrease the cost per examination.
2. ***The use of a detector shape as close as possible to the size and shape of the human body*** (e.g. elliptical for the torso and a detector ring with a smaller diameter for the

head), saves costs in the detector and improves photon detection capabilities which have to travel a shorter distance from the body to the detector, thus randoms can be reduced because a shorter time interval between two photons hits can be set. The 3D-Flow DSP capabilities can perform a good DOI measurement providing higher resolution at a lower cost than what would have been achieved by using a detector with a wider diameter ring and no DOI measurements.

### Acronyms:

3-D Complete Body Scan (**3D-CBS**); Arithmetic Logic Unit (**ALU**); Avalanche Photo Diode (**APD**); Bismuth Germanium Orthosilicate (**BGO**); European Center for Nuclear Research (**CERN**); Constant Fraction Discriminator (**CFD**); Central Processing Unit (**CPU**); Cesium Iodide (**CsI**); Computed Tomography (**CT**); Depth of Interaction (**DOI**); Digital Rectal Examination (**DRE**); Digital Signal Processing (**DSP**); Electronic Design Automation (**EDA**); Food Drug Administration (**FDA**); Field Programmable Gate Array (**FPGA**); Fluorodeoxyglucose (**FDG**); First-In-First-Out (**FIFO**); Field Of View (**FOV**); Gallium Arsenic (**GaAs**); General Electric (**GE**); Gross Domestic Product (**GDP**); Health Care Financing Administration (**HCFA**); Health Maintenance Organization (**HMO**); Intellectual Property (**IP**); Line of Response (**LOR**); Lutetium orthosilicate (**LSO**); Multiply Accumulation Unit (**MAC**); Magnetic Resonance Imaging (**MRI**); Thallium-activated Sodium Iodide (**NaI(TI)**); National Health care Expenditures (**NHE**); Positron Emission Tomography (**PET**); Printed Circuit Board (**PCB**); Pulse Height Discrimination (**PHD**); Prostate Specific Antigen (**PSA**); Pulse Shape Discriminator (**PSD**); System-On-a-Chip (**SOC**); Superconducting Super Collider (**SSC**); Time-to-Digital converter (**TDC**); United States of America (**USA**); Yttrium Orthosilicate (**YSO**).

### About the author:

Dario Crosetto has collaborated for the past twenty years in extensive physics experiments at the European Center for Particle Physics (CERN) in Geneva and at the Superconducting Super Collider Laboratory (SSCL) in Texas, U.S., and has designed the critical part of the electronics (recognizing particles arriving at million events per second) for experiments costing up to half a billion dollars (see the Gammas Electrons and Muons Technical Design Report –GEM TDR- at www.3d-computing.com/pb/gem-tdr.pdf and [50], [51]). He has been designated principal investigator of government grants, the largest of which was $750,000. He was responsible for the implementation of an Application Specific Integrated Circuit (ASIC) for a physics experiment (where thousands of those ASICs are now in use). He has designed a DSP parallel processing system for the trigger of physics experiment, and this design, subsequently entered into the commercial market, was used by a German company in applications for quality control in lamination processes. He improved the electronics of other PET and other applications for medical imaging devices during the past ten years.

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