

Performance Safety Indicators for a Radioactive Facility in Cuba

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Abstract

There is not an integrally control and assessment of the radiation safety management system in the Center of Isotopes, the biggest of radioactive facilities in Cuba. The establishment and use of performance radiation safety indicators could contribute to the solution of this problem. With Delphi method are approved 51 indicators and their evaluations are executed. All those areas of the radiation protection program are considered (e.g. licensing and training of the staff, occupational exposure, authorization of the practices, control of the radioactive material, radiological occurrences, monitoring equipment, radioactive waste management, public exposure due to airborne and liquids discharges, audits and safety costs). In addition to analyze the changes and trends, these indicators are compared against identified thresholds to evaluate performance strengths and weaknesses. The insertion of these indicators in the balanced scorecard for the first time allows measurement of efficacy and efficiency of all this system in a radioactive facility.

Keywords: Performance indicators, radiation safety, radioactive facility, Delphi method.

Introduction

Over the last fifteen years the Centre of Isotopes (CENTIS) of the Republic of Cuba has been manufactured of a wide range of radioactive products for healthcare, life science research and industrial applications and there has been realized biodistribution and pharmacokinetic studies. Besides, this centre has been the main consignor and carrier of radioactive material in our country. A safety management system (SMS) was implemented to cover the CENTIS' functions. This is intended to establish and document in a systematic and structured way the framework of control applied to satisfy the radiation protection requirements and provisions established in the regulations [1÷7]. In spite of this, there is not an integrally assessment of its performance and a way for the continuous improvement. Carry out self-assessment to evaluate the performance of work and the improvement of the safety culture is a good practice. The effectiveness and efficiency of the existing process should be evaluated and analyzed. For this purpose data is collected for a set of safety performance indicators. Using specific performance indicators by each basic element of this system could be possible to obtain this goal.

Materials and methods

Selection of PI

In the selection of performance indicators (PI) for radiation safety process is used the Delphi method [8]. For the elaboration of interview are taking into account the basic elements of the radiation protection program and results of audits and controls of safety costs. This interview was evaluated by an expert committee. The expert committee is selected considering radiation safety specialists, experience of work, training in radiation protection and labor in CENTIS. In particular, it is calculated the coefficient of concordance, C_i , among experts for each indicator, as equation [8] $C_i = 1 - V_n/V_t$, where V_n and V_t are negative vote and total votes, respectively. If $C_i > C_{\text{Approach}}$, the indicator is accepted. The last is taken as 0.8 for obtaining the prevalence of a decision of experts in each indicator.

Evaluation of PI

Each accepted PI is evaluated from a database conformed by necessary information. Collecting data are obtained from registers and periodically updated. Quarterly indicators and annual indicators are calculated. ^{131}I , ^{99}Mo and ^{32}P are the radionuclides used about 12 years in CENTIS or their contribution to occupational exposure is not low. The effective collective dose or collective dose of centre by year (S) was determined following the expressions mentioned for the International Commission of Radiation Protection [9]. Taking into account [10] and statistics of occupational exposure in CENTIS was adopted as dose constraint of equivalent dose to lens of eyes equal 15 mSv. Average annual effective dose (E) of 1.46 mSv and the respective handling activity of ^{131}I as $1.22\text{E}+13$ Bq from Nuclear Research Institute (IPEN) of Brazil in 1980 are used as references to analyze the behavior for CENTIS [11]. Radiological occurrence are registered, classified and analyzed from their cause point as human error and fault of equipment. The occurrence is classified as incident when there is an additional exposure superior to the register level. Safety costs are calculated taking into account the annual financial resources for radiation protection services and buys. Costs from licensing of staff and practices are included.

Results and discussion

PI selected for CENTIS

The expert committee selected is integrated by 5 members with 9.78 average years of experience. There is a unanimous vote in the interview and using equation 1, C_i is equal 1. The amount of 51 PI for the SMS is approved. The Table 1 shows full amount PI by each basic element of SMS. It can be appreciated that the control of occupational exposure has the biggest quantity of PI due to its significance for the accomplishment of the safety policy. In the Table 2 is shown the twelve of them which are included in the balanced scorecard of Occupational Safety and Health System (OSHS). The PI numbered as 2÷3 and 6÷8 in this table are selected for the Direction of CENTIS.

Table 1. Total Indicators by Basic Element of the Radiation Safety Management System

Basic element	Total indicators	Basic element	Total indicators
Authorization and capacitating of staff	4	Control of public exposure due to liquid discharges	3
Authorization of practices	2	Control of public exposure due to airborne	4
Control of radioactive inventory	2	Radiological occurrence	6
Control of Occupational exposure	12	Auditory	3
Radiological Workplace Surveillance	3	Control of safety costs	1
Verification of radiation protection equipment	2	Security	2
Management of radioactive wastes	5	Safeguards	2

Results of evaluation of PI selected for CENTIS

In table 3 is presented the relationship between the behavior of annual handling activity (of ^{131}I , ^{99}Mo and ^{32}P) and S. In spite of increasing 2.6 times for the sum of activities of ^{131}I and ^{32}P in

the last two years, S only has an increment up to 2.3 times. Figure 1 shows S' liaison with the number of monitored workers (w). The increase of personnel implies the same behavior of S, but reduces E. The increment of individual radiation doses ^{32}P contributed to $75.4\text{E-}03 \text{ man-Sv y}^{-1}$ in 2003. Besides, it should be observed in the figure 1 the appreciable reduction of the individual exposures determines the decreasing of S during 2006÷2008. In spite of this, there is the biggest value $98 \text{ man-mSv y}^{-1}$ in 2010 due to the increment of ^{131}I activity.

Table 2. Safety Performance Indicators for the Balanced Scorecard of Occupational Safety and Health System

N	Indicator	Thresholds		
		(Green) Efficient management band	(Yellow) Acceptable management band	(Red) Unacceptable management band
1	Percentage of workers with next expiration of authorization	< 10 %	< 20 %	NA
2	Percentage of practices with next expiration of authorization	< 10 %	< 20 %	NA
3	Maximum dose (E, Hp(0,07) and Hp(3)) to dose constrain for each group of workers	< 1	1	NA
4	Percentage of point with parameters $X < NR$	$\geq 90,0 \%$	$\geq 80,0 \%$	NA
5	Percentage of ready equipments	100 %	$\geq 90,0 \%$	NA
6	Annual release rate to unconditional clearance levels for liquid discharges ratio	< 1	1	NA
7	Annual release rate to unconditional clearance levels for airborne discharges ratio	< 1	1	NA
8	Number of events per month with category superior to anomaly	< 4	<5	NA
9	Test of radiological emergency plan	Yes	NA	No
10	Amount of violation in security procedure in handling of radioactive materials o radioactive packages	0	≤ 2	Yes
11	Existence of fail in the alarm system in doors of vehicles for radioactive materials transport	0	NA	NA
12	Updated declaration of site for CENTIS	Yes	NA	No

It was estimated an annual collective dose of $200\text{E-}03 \text{ man-Sv}$ [12]. Table 3 allows seeing the biggest figure of S is 0.49 times lower than this value. This is caused by CENTIS yet does not reach to the maximum activity of the basis its design for ^{99}Mo and ^{32}P . Groups of Radiopharmacy and Quality Control are the most contribution to S. Their S for E equal or superior 2 mSv is $9\div53 \%$ of total S. It can be appreciated in Figure 2 there is a larger medium

value of S for the group of Radiopharmacy in 2002÷2003, 2005 and 2009÷2010, as a result of the increment in handling activities before analyzed. The biggest contribution to occupational exposure belongs to production of Technetium generators. The percentage of the monitored workers organized by adopted E' intervals can be seeing in the Table 4. For the purposes of this work, monitored workers are people to whom a dosimeter was issued. For the majority of workers (equal or more than 63 %), there is E below 2 mSv y⁻¹. Temporal distribution of the hand equivalent dose (Hp(0.07)) is shown in figure 3.

Table 3. Performance Indicator: Relationship between the Behavior of Annual Handling Activity and Collective Dose

Year	Handling activity of ¹³¹ I (Bq y ⁻¹)	Handling activity of ⁹⁹ Mo (Bq y ⁻¹)	Handling activity of ³² P (Bq y ⁻¹)	S (man-Sv)
1996	No handling	3.20E+11	No handling	0.025
1997	7.33E+11	5.92E+11		0.016
1998	4.90E+12	5.39E+11		0.039
1999	4.87E+12	6.60E+11	1.19E+10	0.030
2000	4.84E+12	5.35E+11	3.64E+11	0.054
2001	4.88E+12	1.38E+12	3.43E+11	0.036
2002	4.60E+12	1.59E+12	2.35E+11	0.063
2003	3.94E+12	1.49E+13	2.35E+11	0.075
2004	4.71E+12	2.73E+13	1.93E+11	0.026
2005	4.08E+12	2.77E+13	9.75E+10	0.035
2006	3.28E+12	2.29E+13	5.45E+10	0.022
2007	4.91E+12	2.52E+13	8.27E+10	0.017
2008	4.33E+12	2.32E+13	2.03E+11	0.018
2009	5.76E+12	4.01E+13	2.24E+11	0.042
2010	7.09E+12	3.19E+13	3.17E+11	0.098

The relationship between the maximum annual value of dosimetric quantities and their respective dose constrains can be observe in table 5. In 1996 and 1997 it is indicated as not controlled (NC) for Hp(3). The biggest values appear in year 2000 for E, 2006 for Hp(0.07) and 2003 for Hp(3). It should be appreciated that dose constrains are overcome in these two first moments. A worker of the group of Quality Control made all of the elution of generators and received 25.77 mSv, value superior of the limit as average for 5 years [1]. The work load was redistributed and a shielding of lead with 5 cm was situated. In the second case the procedure of intervention in hot cell with ¹³¹I was analyzed. There was an incorrect manipulation for part of worker and this is the cause of the biggest value of Hp(0.07). Some PI for radioactive wastes generation is illustrated in figures 4÷5. The first shows the relationship between generation and clearance of radioactive wastes. It can be seen that the biggest value of this indicator presents in the first semester of 2011 and it is an unacceptable value because it indicating there is a limited capacity for temporal storage of these wastes. The volume of radioactive wastes per worker for each department is an indicator which allows easily identifying those practices with the biggest contribution. As can be observed in figure 5, the production of radiopharmaceuticals and the service of the Department of Clinical Diagnostics are the most major generators. In the other hand, it should be verified if the increasing of productions induces the same behavior in the generation of radioactive wastes.

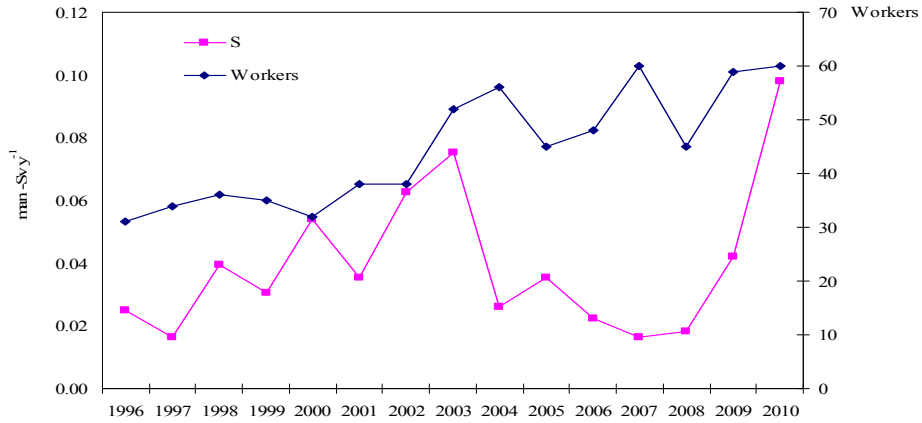


Figure 1. Performance indicator: Relationship between the Collective Dose and Amount of Workers by Year

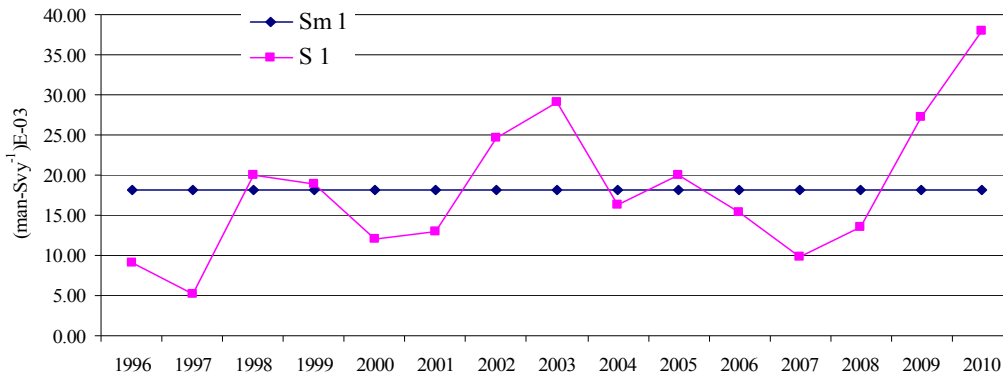


Figure 2. Performance indicator: Collective Dose for the Group of Radiopharmacy (S1) to Medium Collective Dose of this (Sm1) Ratio

In the table 6 can be appreciated the relationship between CENTIS and IPEN (Brazil) from the correlation activity versus occupational exposure. When activity in CENTIS overcomes the value for IPEN, its exposure maintaining below of the IPEN and this is a good behavior. This not occurs in 2000, 2002, 2003 and 2010. The relationship between annual handling activity of ¹³¹I and percentage of liquid effluent management as radioactive wastes is shown in Table 7. This radionuclide is the most contribution in the activities of these waters and very frequently conduce increase above the clearance level of specific activity 0.0623 Bqm⁻³. The public exposure derived to airborne discharge is evaluated for a critical group and normal operation conditions [12]. For maximum activity levels of each involved radionuclide for these releases, is estimated an annual effective dose of 1μSv. The ¹³¹I contribution for this exposure represents an 88.5% (the maximum activity of this radioisotope is 8.14E+07 Bq). Lineally extrapolation is used for the dose assessment. In figure 6 can be observed that maximum figure is registered in 2002. This occurs with a 37GBq of ¹³¹I in a type A package, due to manipulation of its broken first containment during the opening of this in controlled zone. The maximum radioactive concentration of ¹³¹I registered is 29.9 Bqm⁻³ and this was in 2009. This value is lower than authorized level (59.4 Bqm⁻³). The allowed annual activity level for airborne discharge of this radionuclide is 100 MBq [13] and this value is respected. It can be perceive that the dose constrain of 10 μSv a-1 is also respected.

Table 4. Performance indicator: Percentage of the Monitored Workers Organized by Interval of E

Year	Percentage of monitored workers (%)			
	E < 2 mSv	(2 ≤ E < 6) mSv	(6 ≤ E < 12) mSv	(20 ≤ E < 50) mSv
1996	87	13	0	0
1997	94	6	0	0
1998	86	14	0	0
1999	83	17	0	0
2000	84	13	0	3
2001	95	5	0	0
2002	63	34	3	0
2003	81	19	0	0
2004	95	5	0	0
2005	89	9	2	0
2006	94	4	2	0
2007	98	2	0	0
2008	98	2	0	0
2009	90	10	0	0
2010	72	28	0	0

There is an annual maximum figure of five incidents per year during 2001 and 2002. This tendency can be observed in figure 7. Over the last fourteen years, the 49% of these occurrences are due to human mistake. The biggest values of workers and first responder's doses are 2.23mSv as E; 0.7mSv as committed effective dose (E(50)) and 50.49mSv as Hp(0.07). There were four incidents in 2006÷07 although it was registered the lowest annual occupational exposure in 2007. This certainly indicates the effectiveness of the adopted actions which allows maintain null this amount for the rest of studied period. Figure 8 hows the relationship between collective dose and safety costs in Cuban pesos and CUC by year. It can be determinate safety costs reduce S in years 2004 and 2007. In the rest of years can not observed influence of this. The maximum import in Cuban pesos appears in 2004 and in CUC in 2007. Starting 2008 in these costs are included the salaries of radiation protection specialists. Between 2008 and 2009 and 2009 and 2010, S increase 2.3 times, which is significant. In spite of this, the cost in both currencies was reduced. As strategy, this behavior should be changed and to be determined more efficient options to reduce S.

For the periodical retraining of staff is introduced the analysis of PI as a tool for get better the feedback process and training [14]. This kind of process is realized each two years.

Among 28 annual indicators only the percentage of critical non-conformances is in an unacceptable management band because it is bigger than 30 %, value taken as a reference. For this reason, CENTIS' safety management system is in the acceptable band. In spite of this, it is necessary upgrading the relation between generation and clearance of radioactive wastes and safety costs as a function of collective dose.

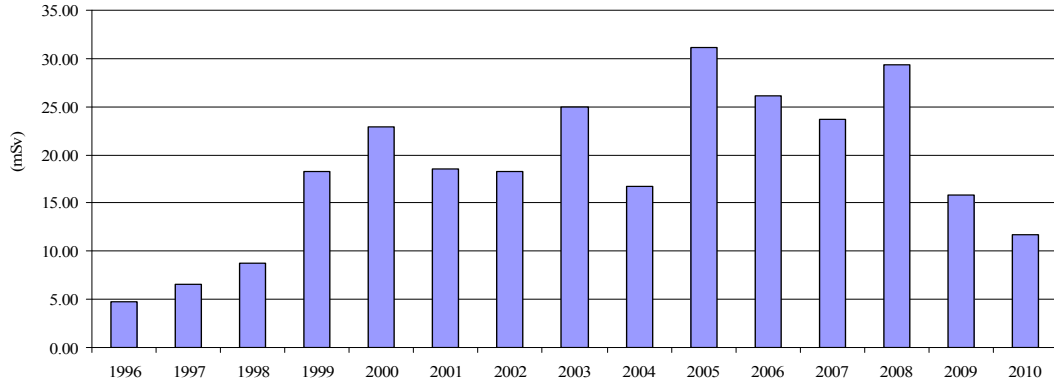


Figure 3. Performance indicator: Mean Annual Equivalent Dose to Hands

Table 5. Performance Indicator: Maximum Annual Value of Dosimetric Quantities to the Respective Dose Constrain Ratio

	E (mSv)	Hp(0.07) (mSv)	Hp(3) (mSv)
Dose constrains	12	200	45
Year			
1996	4.73	8.15	NC
1997	4.02	8.56	NC
1998	10.27	17.85	2.60
1999	4.85	49.38	4.38
2000	25.77	65.43	1.27
2001	3.22	117.97	1.90
2002	7.06	97.94	8.47
2003	5.89	91.47	12.09
2004	4.17	73.41	5.14
2005	6.52	145.17	5.89
2006	6.09	232.71	3.49
2007	2.96	117.70	3.86
2008	4.28	168.38	2.18
2009	5.32	172.49	4.85
2010	5.14	60.68	3.85

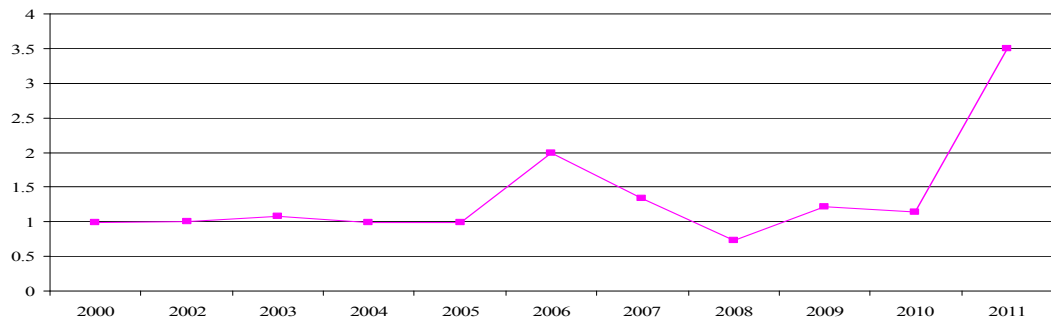
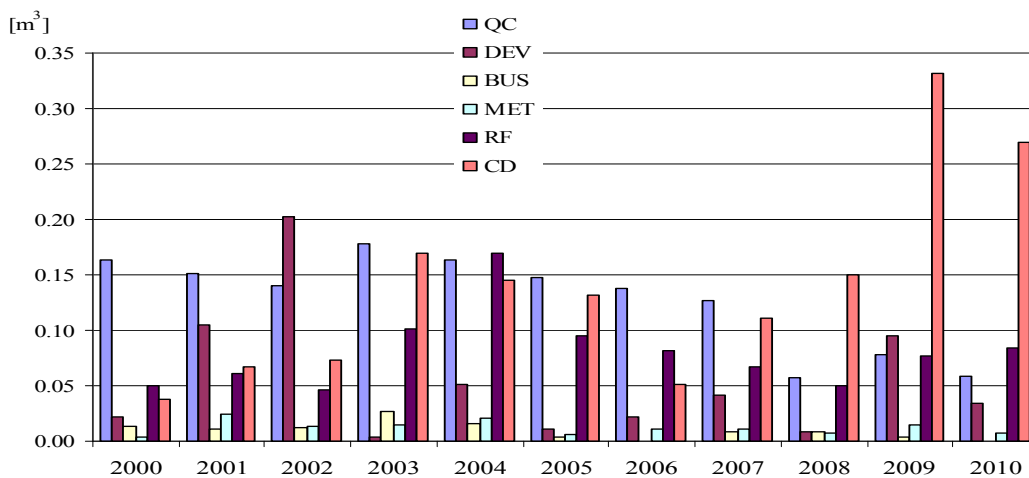


Figure 4. Performance Indicator: Generation to Clearance of Radioactive Wastes Ratio

Table 6. Threshold for Performance Indicator: Annual Handling Activity in CENTIS to IPEN Ratio and Mean E for both of them Ratio

Year	Activity CENTIS vs. Activity IPEN	Mean E CENTIS vs. Mean E IPEN
1996	0.03	0.55
1997	0.11	0.32
1998	0.45	0.71
1999	0.45	0.60
2000	0.44	1.15
2001	0.51	0.64
2002	0.51	1.13
2003	1.54	1.01
2004	2.62	0.32
2005	2.60	0.54
2006	2.14	0.35
2007	2.47	0.19
2008	2.25	0.28
2009	3.76	0.51
2010	3.19	1.12



(a) QC, Department of Quality Control; DEV, Department of Development; BUS, Department of Business; MET, Department of Metrology; RF, Department of Radiopharmacy; CD, Department of Clinical Diagnostics

Figure 5. Performance Indicator: Annual Generation of Radioactive Wastes by Laboratory for each Department

Conclusions

The implementation of radiation safety management system in CENTIS, the biggest radioactive facility of Cuba, is to enhance the safety performance in an organization that leads to the development of a safety culture, in line with the spirit of regulations. Safety performance indicators are tracked, trended, evaluated and acted upon. These are a good tool to monitor the SMS' health, but its use shall be subjected to quality control and verification. The analysis of PI's behavior in the training of the staff is a good experience since this allows improvement the feedback process. Radiation safety audit will also help to identify the deviations of radiation protection program and to take necessary action to fulfill the regulatory requirements. Until

today the evaluation of this system has identified CENTIS is an acceptable management band, but there are some aspects to perfection like the radioactive wastes management, safety costs and results of safety audits.

Table 7. Performance Indicator: Relationship between Annual Handling Activity and Percentage of Liquid Effluent Management as Radioactive Wastes

Year	Handling activity of ^{131}I (Bq y^{-1})	Medium concentration of ^{131}I (Bq m^{-3})	Volume (m^3)	Percentage of effluent management as radioactive wastes (%)
1998	9.99E+10	1.71E-01	38.0	65.0
1999	1.08E+11	1.29E-01	73.3	81.3
2000	1.03E+11	8.16E-02	30.0	46.7
2001	9.97E+10	7.99E-02	38.0	21.1
2002	7.80E+10	3.75E-01	26.0	55.6
2003	8.21E+10	5.58E-02	22.0	100.0
2004	1.13E+11	2.74E-02	27.8	95.5
2005	9.06E+10	8.28E-01	32.0	87.5
2006	7.19E+10	5.31E-03	22.0	88.9
2007	1.04E+11	1.47E-02	36.0	28.6
2008	9.09E+10	1.05E-01	36.0	31.3
2009	1.34E+11	6.36E-02	14.0	57.1
2010	1.48E+11	4.50E-01	18.0	40.0

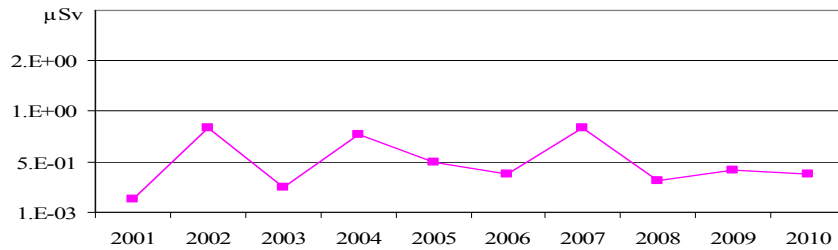


Figure 6. Performance Indicator: Annual Effective Dose of Public due to Airborne Discharges

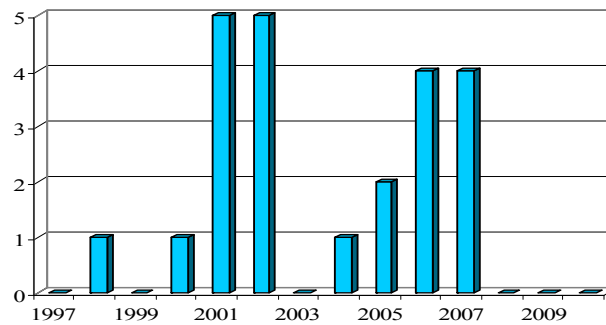


Figure 7. Performance Indicator: Number of Radiological Incidents by Year

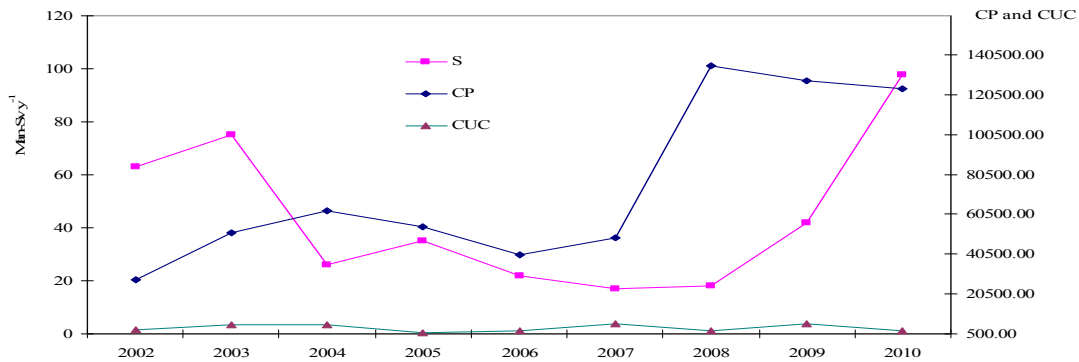


Figure 8. Performance Indicator: Relationship between Collective Dose and Safety Costs in Cuban Pesos and CUC by Year

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