

FINANCING OF RADIOACTIVE WASTE DISPOSAL IN THE CZECH REPUBLIC

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INTRODUCTION

In 1997 in the Czech Republic came in force a new Atomic Act – the Act No. 18/1997 Coll., “On Peaceful Utilization of Nuclear Energy and Ionizing Radiation”. Among the other provisions the Act has established new state policy in the field of radioactive waste management. A new state organization, the Radioactive Waste Repository Authority (RAWRA), which is responsible for radioactive waste disposal, has been established in June 1997.

The provisions of the Act clarify the relations between radioactive waste generators and state, and define explicitly duties of waste generators. One of their most important duties is to cover all expenses for radioactive waste management now and in the future, including radioactive waste disposal and decommissioning of nuclear facilities. For a cumulation of financial resources from waste generators, to cover costs on disposal of their radioactive waste, a special state fund - the “Nuclear Account” has been established. To assure sufficient financial resources for decommissioning of nuclear installation, their owners are obliged to create a special reserve within their accounting and budget.

The existing radioactive waste repositories shall be transferred to the State ownership and operated by RAWRA no later than in June 2000. RAWRA is responsible also for administration of levies to the Nuclear Account, which includes also development of calculation formula and calculation of individual levies. The administration of levies and the Nuclear Account is regulated by the governmental directive No. 224/97 Coll., where are laid down the basic provision on relations between RAWRA and waste generators. RAWRA is responsible for preparation of a proposal of a new regulation that should replace the present one, after a transfer of the repositories into property of the State, and start of their operation under RAWRA.

The following few paragraphs show in brief the new approach to the levies assessment in the Czech Republic which uses a basic mathematical apparatus – linear programming. Following paragraphs are a summary of a previous work called “The Methodology for Calculation of Levies to the Nuclear Account” published at the Economic University in Prague as a diploma work, that was developed in accordance to needs of RAWRA.

The goal of the work is to provide a basic methodology for the levies assessment, that includes a tool for establishing of some qualitative criteria and their weights if needed. For this purpose a self-generating mathematical model is created, which uses all the inputs, creates a certain mathematical algorithm and offers results (which quality depends on the quality of the input data).

THE CASH FLOW IN THE SYSTEM

By the **system** are meant all the elements of organization and management of the RW disposal process. The financing of the whole system from the establishment till the termination is ensured by collecting financial resources at the nuclear account. The nuclear account has two sides:

1. **expenditure side**
2. **income side**

The transfer of finance to and from two sides of the nuclear account represents cash flow in the system. On the expenditure side are recorded transfers from the nuclear account – **expenditure**, on the income side are recorded transfers to the nuclear account – **income**. The goal of the nuclear account is to assure sufficient financial resources for assuring the primary function of the system – **the safe RW disposal and activities connected with it**.

EXPENDITURE

The analysis of expenditure side of the nuclear account, the quantification and description of expenditure are the most important factors for the exact assessment of the desired income into the system and therefore the most important factor for the assessment of the levies.

The expenditure side of the nuclear account is constituted of these types of expenditure:

Non-investment expenditure

By non-investment expenditure are meant the financial resources spent on securing the common functions of RAWRA. Among non-investment belong all financial resources essential for securing the everyday operation of repositories (operating expenditure).

Investment expenditure

By investment expenditure are meant the financial resources spent on planned or unplanned investment projects. The most important and expensive investment project is a construction of a underground repository. But there are other investment projects such as investment into modernizing the existing RW repositories.

INCOME

Financial resources flowing into the system represent the income side of the nuclear account. These resources are deposited on the nuclear account with the goal to cover all the necessary expenditure.

The Atomic law defines all possible types of income:

- a) Financial resources obtained from the RW generators
- b) Interest from the nuclear account
- c) Revenue from operations on the financial market
- d) RAWRA income
- e) Subventions, donations, grants, etc.

For the purposes of the methodology, everything, except the levies, is called the **other income**. **Income** is called the total income (levies + other income).

CATEGORIZATION OF RW

Before the levies assessment we need to **group** RW into concrete **RW categories**. For these concrete RW categories are then calculated adequate **levies**.

It is possible to choose from a wide range of criteria (for example: activity, half-life time, radiotoxicity, etc.). After selecting relevant criteria, the model generates **several RW categories**.

MODEL FOR LEVIES CALCULATION

The model for levy calculation is supposed to provide a price list, in which for each RW category is determined the price for a RW unit. The categorisation process is a process, which combines **accepted**

criteria and creates RW categories so that any generated RW can belong into one of the categories. In the model we use:

K_i ... accepted criteria for $i=1,2,\dots,k$

k ... the number of accepted criteria

Each of the criteria divides into **sub-criteria**:

K_{ij} ... $j=1,2,\dots,k_i$

k_i ... the number of sub-criteria in the i -th criterion for $i=1,2,\dots,k$

After combining every criterion we get n RW categories:

$$n = \prod_{i=1}^k k_i$$

Each category is identified by a number code. The code is k numbers long and on the i -th position of the code is the concrete value of the sub-criterion in the i -th criterion.

$$(a_1 a_2 a_3 \dots a_k)$$

This specific number configuration is used for weight assessment of every **RW category**.

WEIGHTS IN THE MODEL

There are two types of weights in the model:

1. **The criteria weights**
2. **The RW categories weights**

The criteria weights determine the importance of the criterion and are the base indicator for the RW categories weights calculation. The RW category weights determine the portion of each RW category on the total expenditure.

The quantification of weights for criteria and sub-criteria is a rather complicated process which supposes co-operation of a large group of experts in various fields. Those experts quantify the weight of every single criterion using various methods such as the Saaty method. Weight is assigned to every RW category. As above every RW category is described by its code. Numbers in this code determine the value of the concrete RW category weight:

$$v(a_1 a_2 \dots a_k) = \frac{v_1 w_{1a_1} + v_2 w_{2a_2} + \dots + w_k w_{ka_k}}{\sum_{i=1}^k \sum_{j=1}^{k_i} v_i w_{ij}}$$

THE ROLE OF TIME IN THE MODEL

Time and its flow play an important role in the whole system. The dynamics of the whole process is inherent in these areas:

1. **Expenditure time diversification**

Expenditure is irregularly diversified through the time. This irregularity is caused for example by high investments for the construction of the underground repository.

2. **RW production time diversification**

The amount of produced RW is changing during the time. Within the framework of our system the amount of produced RW represents demand for RAWRA services.

3. Income time diversification

The total amount of finance flowing into the system is dependent on RW production, as the RW production is the main determinant of RAWRA income.

4. Inflation

Inflation plays an important role in devaluation of the financial resources deposited on the nuclear account. The time disharmony in the moment of collecting financial resources on one hand and investing these financial resources on the other would lead into gradual decrease of the real value of the financial resources.

5. Income from operations on financial market

The income from the investment of free financial resources from the Nuclear Account keeps the real value of the financial resources and increases their nominal value. The recent discussion is whether the income from investing will cover an inflation only or will be higher (the real value of the deposited money will increase) or will be lower (the real value of the deposited money will decrease). In this methodology version is used the first approach – inflation and investment income are the same.

6. Sufficiency of the financial resources on the nuclear account

The perpetual fluctuation of the economic result (income minus expenditure) is caused by the expenditure and income time diversification. The condition is that the whole system should be self-financing. This condition means that there can be no red numbers on the nuclear account and the levies should assure it.

7. Sufficiency of the financial resources on the nuclear account after RW production termination

Because of the time disharmony between the planed RAWRA operation and RW generators activities lifetime, it is necessary to assure sufficient amount of financial resources on the nuclear account. This final cash balance is essential for financing the system, when no longer any levies will flow to the nuclear account. The dynamics of the whole process is displayed in the following table.

Table I: The dynamics of the process

Years	RW production in RW units				Expenditure	Income	Economic	Cash balance
T	$RW_{1,t}$ - code	$RW_{2,t}$ - code	$RW_{n,t}$ - code		N_t	I_t	result	NA_t
1998	$RW_{1,1998}$	$RW_{2,1998}$	...	$RW_{n,1998}$	E_{1998}	I_{1998}	ER_{1998}	NA_{1998}
1999	$RW_{1,1999}$	$RW_{2,1999}$	...	$RW_{n,1999}$	E_{1999}	I_{1999}	ER_{1999}	NA_{1999}
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T	$RW_{1,T}$	$RW_{2,T}$	...	$RW_{n,T}$	E_T	I_T		NA_T
Total	ΣRW_1	ΣRW_2	...	ΣRW_n	ΣE	ΣI	ΣER	

Levy	p_1	p_2	...	p_n
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$RW_{i,t}$... production of RW of i-th category in the year t ($i=1,2,...,n$)

E_t ... total expenditure in the year t

I_t ... total income in the year t

NA_t ... cash balance on the nuclear account in the year t

NA_T ... final cash balance on the nuclear account in the year T – FCB

p_i ... the price for the disposal of one RW unit in each RW category ($i=1,2,...,n$)

THE CALCULATION ALGORITHM

The goal of RAWRA is to assure sufficient financial resources for financing the RW disposal and before of all the construction of the new underground repository. For all this purposes it is required to cover all the expenditure with income. Whereas the whole process of financing is non-profit we get the following equity:

$$\begin{aligned} E_t &= I_t, \text{ where } I_t = \sum_{i=1}^n RW_{i,t} \cdot p_i + OI_t \\ RW_{i,t} \cdot p_i &= 0, \text{ pro } t=T_s, T_s+1, \dots, T \end{aligned}$$

E_t ... expenditure in the year t

I_t ... income in the year t

T_s ... the termination of the system

T ... the termination of all RW generators

The whole problem of the assessment of levies to the nuclear account can be transferred on a mathematical optimizing model, which **inputs** are:

- The production of RW divided into n categories in concrete years (time series)
- RAWRA expenditure in concrete years (time series)
- RAWRA other incomes in concrete years (time series)

There also **derived quantities** in the optimizing model:

- RAWRA economic result in each year (income minus expenditure)
- Nuclear account's cash balance (cumulative sum of economic results in recent years)

As to fulfil the constraint of self-financing of the whole process it is necessary to assure sufficient financial resources on the nuclear account. This condition says that it is not possible to drop the financial resources on the nuclear account below zero and can be characterized by the following constraint:

$$NA_t \geq 0, t = t_z, t_z+1, \dots, T$$

NA_t ... the nuclear account cash balance

Variables of the optimizing model are the levies for the RW unit for each RW category: $p_1, p_2, \dots, p_n$.

LEVIES CONSTRAINTS

As above the importance of RW category weight is to determine the portion of each RW category on the total expenditure connected with RW disposal.

Table II: The total portion of the RW categories on total expenditure

RW category	RW category weight	Portion on the total expenditure
RW ₁ - code	$v(code)_1$	$v(code)_1 \times \Sigma N$
RW ₂ - code	$v(code)_2$	$v(code)_2 \times \Sigma N$
...	...	...
RW _n - code	$v(code)_3$	$v(code)_3 \times \Sigma N$
Total expenditure in interval 1998...T		ΣN

The sum of financial resources representing the portion of the concrete RW category on the total expenditure is displayed in the third column of the table. After a table transformation we get the following table which comprises levies for the RW unit in each RW category.

Table III: Theoretical levies - p_{iT}

RW category	RW production	RW category weight	Portion on the total expenditure	Levy for the RW unit - p_{iT}
RW ₁ - code	RW ₁	$v(code)_1$	$v(code)_1 \times \Sigma N$	$(v(code)_1 \times \Sigma N) / RW_1$
RW ₂ - code	RW ₂	$v(code)_2$	$v(code)_2 \times \Sigma N$	$(v(code)_2 \times \Sigma N) / RW_2$
...		...	...	
RW _n - code	RW _n	$v(code)_n$	$v(code)_n \times \Sigma N$	$(v(code)_n \times \Sigma N) / RW_3$
Total expenditure in interval 1998...T				ΣN

If we had to analyse the system annually, then we wouldn't require the self-financing constraint and we could consider p_{iT} as the final values (levies) and stop optimizing. Unfortunately these values are only theoretical levies and determine an interval for the actual levies – levy constraints.

The levy constraints are derived from p_{iT} calculated in the table above.

1. Intervals

$$p_{iD} \leq p_i \leq p_{iH}$$

p_{iL} ... lower bound of the interval for concrete levy for $i=1,2,...,n$

p_{iU} ... upper bound of the interval for concrete levy for $i=1,2,...,n$

It is possible to calculate the concrete values of the lower and upper bounds by different transformations of p_{iT} .

Transformations:

• **absolute**

The absolute transformation transforms values p_{iT} by adding or subtracting a given constant from o_{iT} .

$$p_{iD} = p_{iT} - d_i, \text{ where } d_i \in (0, p_{iT})$$

$$p_{iH} = p_{iT} + h_i, \text{ where } h_i \in (0, \infty), i=1,2,...,n$$

• **relative**

The relative transformation transforms values p_{iT} by multiplying values p_{iT} by a given constant.

$$p_{iD} = p_{iT} \cdot d_i, \text{ where } d_i \in (0,1)$$

$$p_{iH} = p_{iT} \cdot h_i, \text{ where } h_i \in (1, \infty), i=1,2,\dots,n$$

- **combination of absolute and relative**

It is possible to combine transformation of p_{iT} .

Table IV: Levy constraints

Lower bound - p_{iD}	O_{1D}	O_{2D}	...	O_{nD}
Levy - p_i	O_1	O_2	...	O_n
Upper bound - p_{iH}	O_{1H}	O_{2H}	...	O_{nH}

$$p_{2D} \leq p_2 \leq p_{2H} \quad p_{nD} \leq p_n \leq p_{nH} \quad p_{1D} \leq p_1 \leq p_{1H}$$

2. Fixed intervals

If it is needed the intervals can be fixed – no transformation is needed

3. Combination of intervals and fixed levies

Some of the RW categories can have fixed levies and some can have interval constraints.

THE OPTIMIZING MODEL

The problem of assessment of the levies can be transferred on a linear optimizing problem. For this transformation it is necessary to define the objective function, variables and constraints.

- **objective function**

$$z = \sum_{t=t_b+1}^T \left(\sum_{i=1}^n p_i \cdot RW_{i,t} + OI_t \right) \rightarrow MAX$$

- **constraints**

$$\sum_{t=t_b+1}^T \left(\sum_{i=1}^n p_i \cdot RW_{i,t} + OI_t \right) \leq \sum_{t=t_b+1}^T E_t + FCB$$

$$SCB + \sum_{j=t_b+1}^t \left(\sum_{i=1}^n p_i \cdot RW_{i,t} + OI_t - E_t \right) \geq 0, \quad t=t_b+1, t_b+2, \dots, T$$

$$p_i \leq p_{iH}, \quad i=1,2,\dots,n$$

$$p_i \geq p_{iD}, \quad i=1,2,\dots,n$$

$$p_i \geq 0, \quad i=1,2,\dots,n$$

- **variables**

p_i for $i=1,2,\dots,n$ (where p_i is constrained)

The characterisation of the model quantities:

$RW_{i,t}$... RW production in a specific category in the year t

E_t ... total expenditure in the year t

OI_t ... other income in the year t

FCB ... desired final cash balance on the nuclear account

SCB ... starting cash balance on the nuclear account

p_i ... levy for the RW unit in the i -th RW category
 p_{iU} ... upper bound for the levy in the i -th RW category
 p_{iL} ... lower bound for the levy in the i -th RW category
 T ... the activity termination of all RW generators
 t_b ... actual period (period in which is the system at the moment)

It was necessary to specify the objective function as maximize (minimize) function as to be able to apply the means of linear programming. The best ways is to maximize the total income of the financial resources flowing into the system. It is clear that maximizing of the income without any constraints would lead into infinite income. That is why there are constraints in the optimizing model, which are securing the non-profit principle (expenditure equals income in the time interval). The time interval that defines the time of the existence of the system is $\langle t_z, T_s \rangle$. This interval comprises two sub-intervals: $\langle t_z, T \rangle$ and (T, T_s) . The equity condition for expenditure and income in the interval $\langle t_z, T_s \rangle$ is

assured by the constraint
$$\sum_{t=t_b+1}^T \left(\sum_{i=1}^n p_i \cdot RW_{i,t} + OI_t \right) \leq \sum_{t=t_b+1}^T E_t + FCB$$
, where the expression on the

right side represents the expenditure of the system in the interval $\langle t_z, T_s \rangle$ and the expression on the left hand side represents the income of the system in the interval $\langle t_z, T \rangle$. During the interval $\langle t_z, T \rangle$ RW generators periodically transfer their levies onto the nuclear account. During the interval (T, T_s) is the function of the system financed only by the financial resources left on the nuclear account in the year T . The total sum of the financial left on the nuclear account equals FCB (final cash balance) and also by the RAWRA other income.

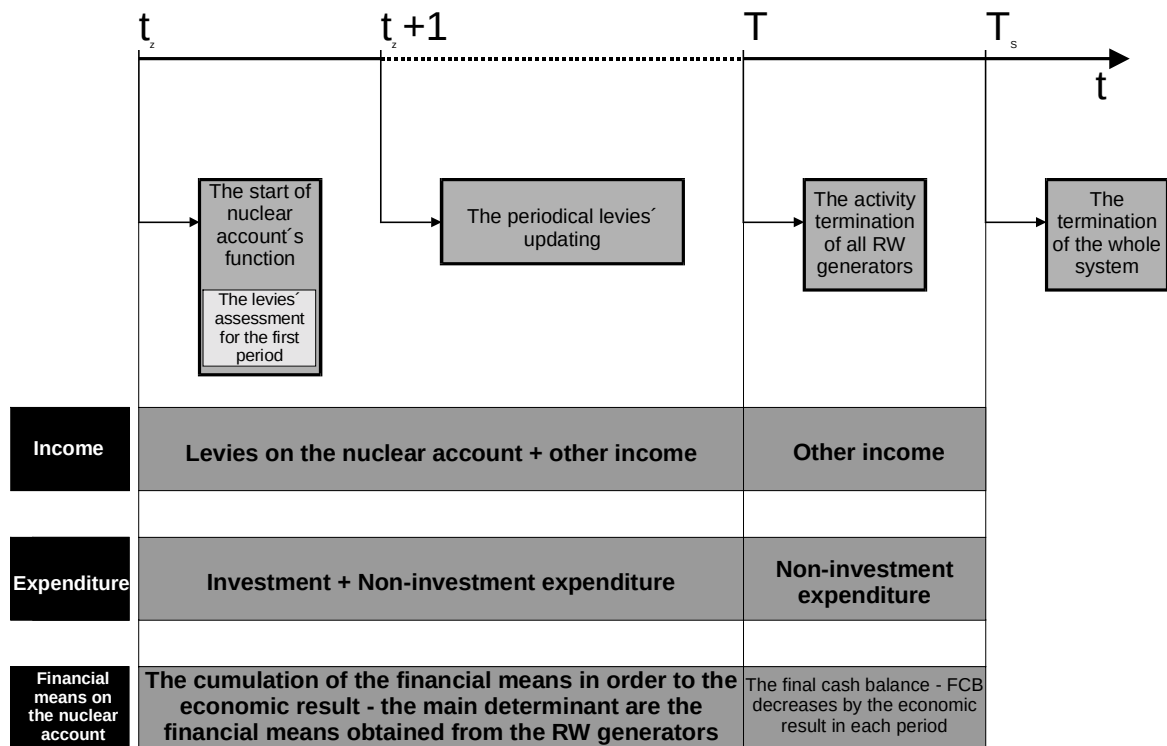


Figure 1: The time schedule of income, expenditure and the financial resources on the nuclear account

The amount of the financial resources deposited on the nuclear account is dependent on the RAWRA economic result in each year (income minus expenditure). It is clear, from the logic of the problem, that amount of the financial resources on the nuclear account will increase from the year t_z (the start of the nuclear account). It will be increase until the expenditure will outbalance the income (this will happen in the period of huge investment into the constriction of the underground repository – expected round 2030). After this outbalance the financial resources on the nuclear account will decrease until the year T , when the main source of income – levies – will stop. The financial resources in the interval (T, T_s) will further decrease from the final cash balance (FCB) till zero. The financial resources on the nuclear account should not drop below zero in the whole interval $\langle t_z, T_s \rangle$. This is assured by the constraint:

$$SCB + \sum_{j=t_b+1}^t \left(\sum_{i=1}^n p_i \cdot RW_{i,t} + OI_t - E_t \right) \geq 0, \quad t=t_b+1, t_b+2, \dots, T.$$

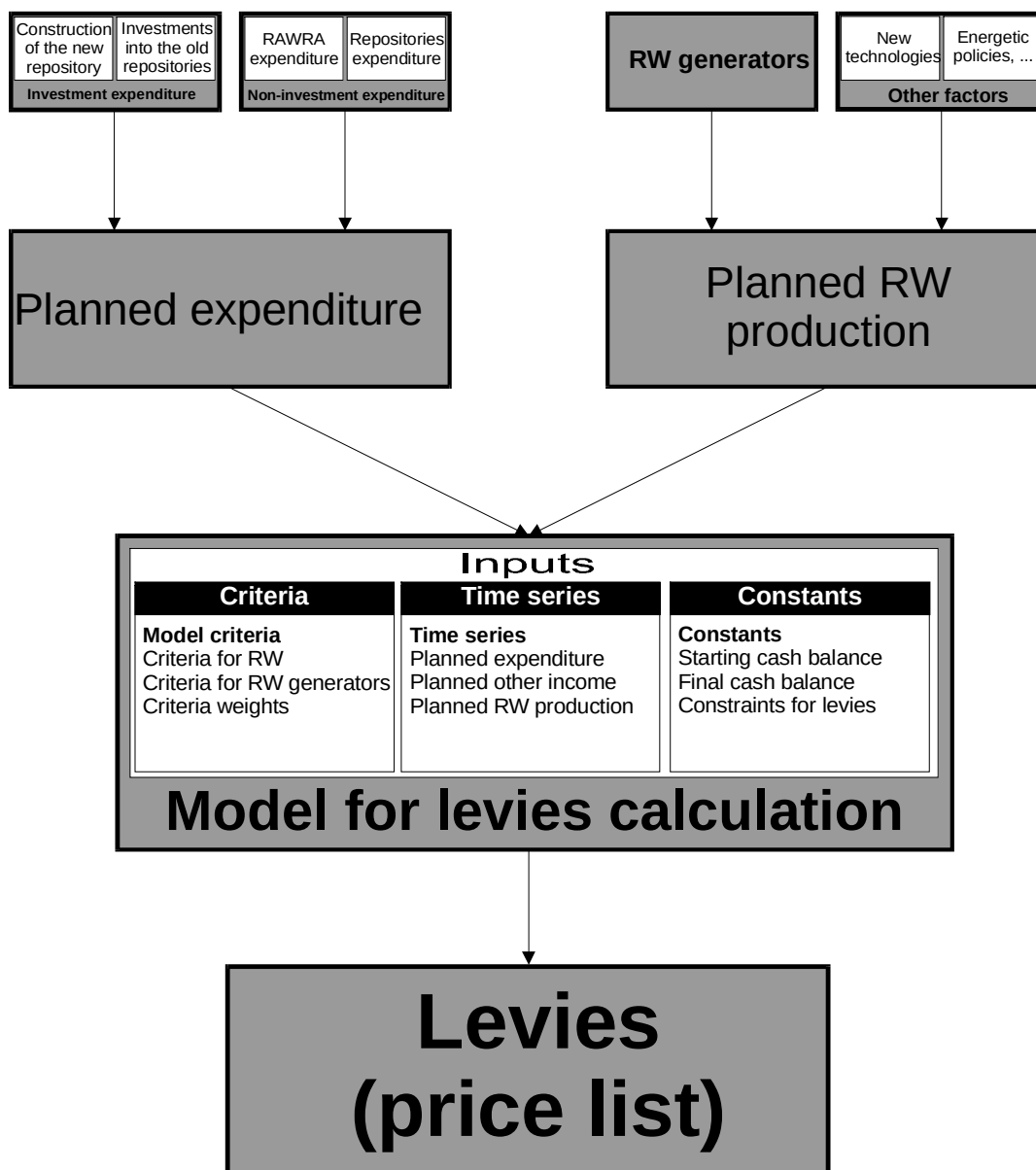


Figure 2: The process of levies calculation

THE START OF THE NUCLEAR ACCOUNT FUNCTION

The start of the nuclear account function should proceed in several preliminary phases, which goal is to provide a sufficient amount of information needed for the assessment of levies:

1. **The definition of RW categories**
2. **The quantification of input information**
 - 2.1. The creation of the RW generators database
 - 2.2. The quantification of expenditure time series
 - 2.3. The quantification of other income time series
 - 2.4. The quantification of other input information
3. **The assessment of levies for the first period**
4. **The notification of levies**

THE ADMINISTRATION OF THE NUCLEAR ACCOUNT

By the administration of the nuclear account is meant the functioning of the nuclear account during the existence of the system.

The operations connected with the functioning of the nuclear account:

- Updating levies on the basis of comparison of the plan and reality
- The assessment of standard procedures for levies collection
- The construction of the payment order for RW generators
- The annual schedule for the nuclear account functioning (assessment and levies collection, proposal for RAWRA expenditure for the government, ...)
- The collection of information relevant to the system
- Other operations (for example the controlling function, ...)

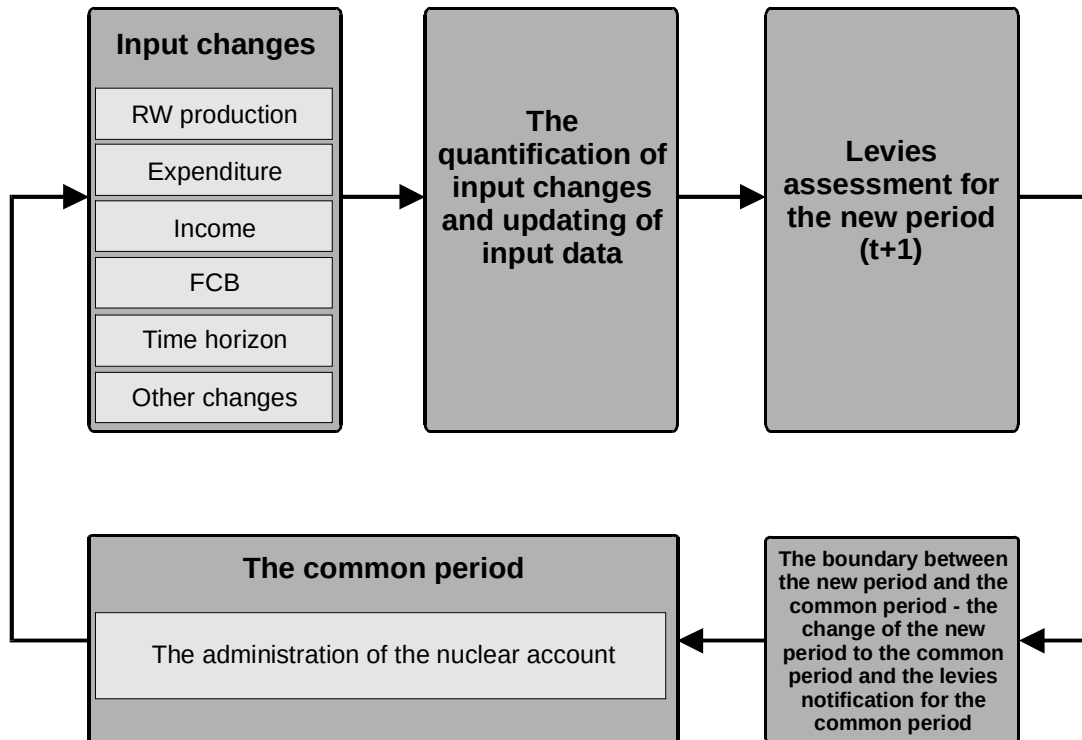


Figure 3: The process of annual updating

All the operations above are very complex and complicated. Especially the operation of updating levies plays a key role and is connected with many sub-operations.

EXPECTED DEVELOPMENT OF THE METHODOLOGY

The model offers one possible look at the substantial problem of levy assessment with its advantages and disadvantages.

The disadvantages of this philosophy are now in discussion. Some of the stakeholders require that the model should be applied so that levy is calculated for each repository separately. The inflation factor and the inflation impact analysis can be implemented into the model. A possibility of a probabilistic risk assessment method implementation is discussed as well.

The success and the precision of the model depend on the quality of all the input data. Therefore, for data qualification and quantification, expert teams in various fields (RW classification, accounting, optimizing, ...) shall be established.

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