



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
21.01.2015 Bulletin 2015/04

(51) Int Cl.:
G21F 9/08 (2006.01) **B01D 1/00** (2006.01)
B01D 3/14 (2006.01) **G21F 9/14** (2006.01)
G21F 9/16 (2006.01)

(21) Application number: **13306011.1**

(22) Date of filing: **15.07.2013**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

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(54) **Method for processing radioactive liquid effluents of a nuclear power reactor and corresponding facility**

(57) The method comprises the following steps:
(18) obtaining a first batch of radioactive liquid effluents;
(20) submitting the first batch to a first evaporation step and producing a first distillate and a first concentrate, the first evaporation step bringing given chemical species and/ or radioactivity concentrations in the first distillate

in respective predetermined ranges;
(22) submitting the first concentrate to a second evaporation step and producing a second distillate and a second concentrate;
(24) recycling the second distillate at the first evaporation step (20) or upstream.

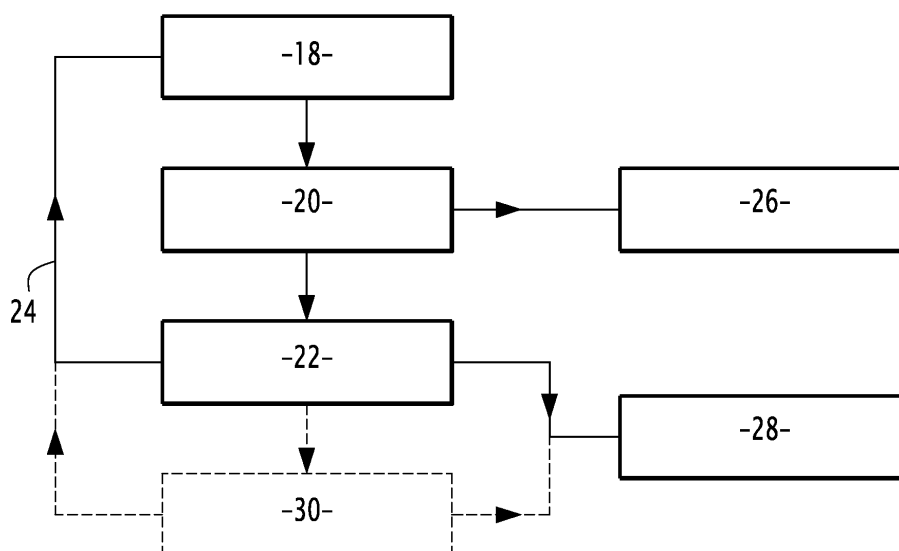


FIG.2

Description

[0001] The present invention concerns the processing of radioactive liquid effluents of a nuclear power reactor.

[0002] More precisely, the present invention concerns according to a first aspect a method for processing radioactive liquid effluents of a nuclear power reactor.

[0003] In a known method depicted on figure 1, different processes are implemented, according to the type of liquid effluent to be treated. The liquid effluents known as "Process drains" are treated by a demineralization process 10 and transferred to a storage tank 12 for radioactivity and chemical content analysis. If the effluents satisfy all environmental requirements, they are released to the environment. The liquid effluents known as "Floor drains" are treated by a filtration process 14 and then sent to the storage 12 for control and release to the environment. The liquid effluents known as "Chemical effluents" are submitted to an evaporation process 16. The distillate is sent to the storage 12 for control and release to the environment. The concentrate is solidified.

[0004] The demineralization process 10, the filtration process 14 and the evaporation process 16 are implemented in a facility known as TEU, which is shared by several nuclear reactors of the power plant.

[0005] The method depicted on figure 1 is satisfactory but generate secondary waste such as spent filter media and spent adsorption media. Other processes for liquid effluent treatment may even generate additionally spent membranes..

[0006] One possible solution for reducing secondary waste volume is processing all the radioactive spent liquid effluents through an evaporator having a high purification performance (decontamination factor). The distillate is released to the environment after chemical and radioactivity content control. Considering the decontamination factor required for the evaporator and the throughput, the equipment required for implementing the evaporation process are large, especially high.

[0007] A particular problem arises when regulatory limits for releasing the distillate to the environment are updated and made harsher. In such a case an increased height of the purification column of the evaporator and thus an increased performance will be limited by the given dimensions of the compartments where the evaporation system is installed.

[0008] The object of the present invention is accordingly to provide a method for processing radioactive liquid effluents of a nuclear power reactor, that generates a reduced volume of secondary waste, and such that a part of the major process equipment for implementing the method can be accommodated in an existing building.

[0009] To achieve that goal, the invention is directed to a method for processing radioactive liquid effluents of a nuclear power reactor, the method comprising the following steps:

- obtaining a first batch of radioactive liquid effluents;

- submitting the first batch to a first evaporation step and producing a first distillate and a first concentrate, the first evaporation step bringing given chemical species and/or radioactivity concentrations in the first distillate in respective predetermined ranges;
- submitting the first concentrate to a second evaporation step and producing a second distillate and a second concentrate;
- recycling the second distillate at the first evaporation step or upstream.

[0010] The basic idea of the invention is therefore to divide the evaporation process in two steps: a first evaporation step for purifying the spent liquid effluents and generating a distillate that can be released to the environment, and a second evaporation step for concentrating the waste for which even a lower decontamination factor can be feasible / acceptable. The predetermined ranges for the given chemical species and/or radioactivity concentrations in the first distillate are chosen to allow the release of the first distillate to the environment. Said final concentrations are as high as possible, but lower than the regulatory limits permitting release of the first distillate to the environment.

[0011] The volume of the first concentrate at the end of the first evaporation step is chosen rather high, since the first concentrate is submitted subsequently to a second evaporation step, allowing for a further volume reduction.

[0012] As a consequence, it is not necessary to use at the first evaporation step an equipment having multiple purification stages for the first distillate, in order to bring said given chemical species and/or radioactivity concentrations in the first distillate in the selected respective predetermined ranges. Indeed, the chemical species and radioactivity concentrations in the first concentrate at the end of the first step of evaporation are moderate. As a consequence, the chemical species and radioactivity concentrations in the first distillate at the end of the first step of evaporation are moderate as well and no extensive purification is required.

[0013] Accordingly, the equipment used for the first evaporation step has a reduced number of purification stages for the first distillate and is less cumbersome. Its height is reduced, and is for example below 8 m.

[0014] By radioactivity, it is understood here either the total radioactivity (without tritium), or the sum of the radioactivity of only a few radionuclides, as a function of the regulation of the area where the nuclear power reactor is located. Alternatively, the radioactivity of several radionuclides can be considered individually, a specific predetermined range being assigned to each radioelement. For chemical species, a specific range is for example associated to each chemical specie or group of chemical species.

[0015] The method may as well presents the following features, considered alone or in combination:

- the radioactivity concentration predetermined range in the first distillate is comprised between 50 and $5 \cdot 10^3$ Bq/l.
- the decontamination factor for radioactivity between the first distillate and the spent liquid effluents is comprised between $5 \cdot 10^2$ and $5 \cdot 10^3$ at the end of the of the first evaporation step.
- the second concentrate is transferred to a solid waste conditioning unit and is submitted to a solidification treatment.
- the solidification treatment comprises a step of drying and /or a step of immobilization of the second concentrate.
- the second concentrate is submitted to a third evaporation step, producing a third concentrate and a third distillate, the third distillate being recycled at the first evaporation step or upstream.
- the radioactive liquid effluents have a radioactivity higher than 10^6 Bq/l.

[0016] According to a second aspect, the invention is directed to a facility for processing radioactive liquid effluents of a nuclear power plant, the facility comprising the following units:

- one or several unit for storing a first batch of radioactive spent liquid effluents;
- one or several first evaporation unit for submitting the first batch to a first evaporation step and producing a first distillate and a first concentrate, the first evaporation step bringing given chemical species and/ or radioactivity concentrations in the first distillate in respective predetermined ranges;
- one or several second evaporation unit for submitting the first concentrate to a second evaporation step and producing a second distillate and a second concentrate;
- one or several unit for recycling the second distillate at the first evaporation step or upstream.

[0017] The facility may as well presents the following features, considered alone or in combination:

- the first evaporation unit is located in an effluent treatment building comprising effluent treatment equipment dedicated to other nuclear power reactors.
- the first evaporation unit has a purification column having a height of less than 8 meter.

[0018] Other features and advantages will be described below, by way of example only, with reference to the accompanying drawings, in which:

- figure 1 is a process diagram depicting a method for processing radioactive liquid effluents of a nuclear power reactor according to the state of the art; and
- figure 2 is a process diagram depicting the method for processing radioactive liquid effluents of a nucle-

ar power reactor according to the invention.

[0019] The process depicted on figure 2 is for processing radioactive liquid effluents of a nuclear power reactor. Said liquid effluents are of different types and come from different sources.

[0020] The so-called "Process drains" come for example from the primary and secondary cooling loops. They have a low salt content, except for boron. The so-called "Chemical effluents" come for example from the regeneration of spent resins. They have a high salt content. The so-called "Floor drains" come for example from process liquids leaks or from liquid used for floor cleaning.

[0021] The process is actually intended to process all kinds of liquid effluents generated in the nuclear power reactor.

[0022] For example, the liquid effluents treated by the process have a radioactivity higher than 10^6 Bq/l, for example comprised between 10^6 Bq/l and 10^8 Bq/l, especially between 10^7 Bq/l and $5 \cdot 10^7$ Bq/l.. However, liquid effluents having a lower or higher radioactivity can be processed according to the invention as well.

[0023] The chemical species content of the spent liquid effluents varies from one batch to another batch, and depends on the type of the nuclear power reactor as well as from the source (e.g. process drains, chemical drains, floor drains).

[0024] As depicted on figure 2, the method for processing radioactive liquid effluents comprises the following steps:

(18) obtaining a first batch of radioactive liquid effluents;

(20) submitting the first batch to a first evaporation step and producing a first distillate and a first concentrate, the first evaporation step bringing given chemical species and/ or radioactivity concentrations in the first distillate in respective predetermined ranges;

(22) submitting the first concentrate to a second evaporation step and producing a second distillate and a second concentrate;

(24) recycling the second distillate at the first evaporation step (20) or upstream;

[0025] The first batch is received and stored in a storage tank. After analysis, for example for assessing the chemical content and the radioactivity level of a number of given radionuclides, the first batch is fed to the first evaporation step 20.

[0026] The first evaporation step is carried out typically in a fed batch fashion. The liquid effluents are continuously fed into an evaporation equipment, with no extraction of the concentrate. The liquid effluents are heated, so that a vapor phase is evaporated and the liquid effluents form the first concentrate. As a part of the first evaporation step, the vapor phase passes through several purification stages, for example in a purification column,

and forms the first distillate at the exit of the purification stages. At each purification stage, a part of the residual chemical species and of the residual radioactivity is separated from the vapor phase.

[0027] The concentration of chemical species and of radioactivity increases in the first concentrate as the vapor phase progressively evaporates. In a parallel manner, the concentration of chemical species and of radioactivity increases in the first distillate. The first evaporation step is stopped at a point selected or given as discharge limit by the related national authorities, so that the given chemical species and/ or radioactivity concentrations in the first distillate are in their respective predetermined ranges.

[0028] Said point is determined by following the composition of the first concentrate, for example by periodically sampling and analyzing the first concentrate, to determine the solid dissolved and non-dissolved in the first concentrate or the radioactivity concentration in the first concentrate. Alternatively, said point is determined by following the composition of the first distillate coming out of the purification stages, for example by periodically sampling and analyzing the first distillate or by means of a continuous measurement, to determine given chemical species concentrations in the first distillate or the radioactivity concentration in the first distillate.

[0029] At step 26, the first distillate is collected in a tank and submitting to chemical and radiological analysis to assess whether regulatory requirements are satisfied. If the regulatory requirements are satisfied, the first distillate is discharged to the environment, for example in the sea, a lake or a river.

[0030] The radioactivity predetermined range in the first distillate is chosen to allow for a release of the first distillate to the environment. Typically, it is comprised between 10 and $5 \cdot 10^3$ Bq/l, for example between 20 and 2000 Bq/l. Typically it is possible to achieve distillate concentration between 20 and 100 Bq/l or even lower values.

[0031] The decontamination factor for radioactivity between the first distillate and the liquid effluents is comprised between $5 \cdot 10^2$ and $5 \cdot 10^3$ at the end of the of the first evaporation step, preferably between 1000 and 2000. The decontamination factor depends on the performance required for the purification stages. The examples given here correspond to a specific design case. The decontamination factor could be lower or higher than those indicated above. The decontamination factor is the ratio between the radioactivity of the first distillate and the radioactivity of the liquid effluents. Said decontamination factor is not very high and is normally assured by the transfer of the liquid phase to the vapor phase. In the purification stages of the first evaporation unit entrained droplets are removed from the vapor thus ensuring an effective purification. Considering that the radioactivity concentration in the first distillate is chosen to be as high as possible - while remaining below the regulatory limits for release to the environment - it means that the volume reduction at the first evaporation step is not very high.

[0032] The second evaporation step 22 is carried out in a fed batch fashion. The throughput at the second evaporation stage is much smaller than the throughput at the first evaporation stage, since the ratio between the volume of the first concentrate and the volume of the first batch of radioactive spent liquid effluents may be for example less than 1/6 or even less than 1/60.

[0033] The second evaporation step allows for a further volume reduction. The first concentrate is continuously fed into an evaporation equipment, with no extraction of the concentrate. The first concentrate is heated, so that the first concentrate is further concentrated and form the second concentrate. As a part of the second evaporation step, the vapor phase passes through one or several purification stages, for example in a demister or typical purification stages like e.g. sieve bottoms or packed columns, and forms the second distillate at the exit of the purification stages.

[0034] At step 24, the second distillate is recycled, for example into the storage tank(s) receiving the batches of spent liquid effluents to be fed to the first evaporation step. It is mixed with a second batch of radioactive spent liquid effluents. The second distillate and the second batch mixed together are submitted to the first and second evaporation steps 20, 22. Alternatively the second distillate can be also recycled directly at the first evaporation stage without mixing with the second batch.. It can be recycled as well at any other point upstream the first evaporation step.

[0035] At step 28, the second concentrate is transferred to a solid waste conditioning unit and is submitted to a solidification treatment. It is treated according to the corresponding national norms and standard.

[0036] The solidification treatment comprises for example a step of drying. Drying is advantageous since it allows a further volume reduction. Drying is for example performed in-drum. The second concentrate is filled into one or several drums, and the drum is externally heated. The liquid evaporates, will be condensed and is returned to the liquid effluent storage tanks for treatment by the mentioned evaporation system. After removing a part of the liquid in the drum, more second concentrate is feed to the drum and the liquid will be also evaporated. This process is continued until in the drum remains a solid block of salts and corrosion products. This drum then, according to related national requirements may be packed e.g. into a a High Integrity Container (HIC) or disposed in a deep geological repository.

[0037] Alternatively, the solidification treatment comprises a step of immobilization of the second concentrate. The step of immobilization of the second concentrate comprises for example immobilizing the second concentrate in a concrete matrix.

[0038] In the case huge amounts of second concentrates are produced, due to nuclear power plant design, optionally the second concentrate is submitted to a third evaporation step 30, producing a third concentrate and a third distillate. The third distillate is for example mixed

with a third batch of radioactive spent liquid effluents. The third distillate and the third batch mixed together are submitted to the first and second evaporation steps 20 and 22. Alternatively, the third distillate can be also recycled directly at the first evaporation stage without mixing with the third batch.. It can be recycled as well at any other point upstream the first evaporation step.

[0039] More than three evaporation steps could be implemented, as a function of the liquid effluents throughput and composition.

[0040] The step 30 is depicted in dotted lines on figure 2.

[0041] The invention is directed as well to a facility for processing radioactive liquid effluents of a nuclear power plant, the facility comprising the following units:

- one or several unit 18 for storing a first batch of radioactive spent liquid effluents;
- one or several first evaporation unit 20 for submitting the first batch to a first evaporation step and producing a first distillate and a first concentrate, the evaporation step bringing given chemical species and/ or radioactivity concentrations in the first distillate in respective predetermined ranges;
- one or several second evaporation unit 22 for submitting the first concentrate to a second evaporation step and producing a second distillate and a second concentrate;
- one or several unit 24 for recycling the second distillate at the first evaporation step or upstream.

[0042] Said facility is adapted for implementing the process described above. As a consequence, the units of the facility and the steps of the process are referenced using the same reference numbers.

[0043] If the quantity of liquid effluents to be processed is high, the facility can include several storage units 18.

[0044] Typically, the facility further includes a unit 26 adapted for collecting the first distillate in a tank and submitting the first distillate to chemical and radiological analysis to assess whether regulatory requirements are satisfied. The unit 26 is adapted for discharging the first distillate to the environment, for example in the sea, if the regulatory requirements are satisfied.

[0045] Typically, the facility further includes a solid waste conditioning unit 28 and means for transferring the second concentrate to said unit 28. The solid waste conditioning unit 28 is adapted to submit the second concentrate to a solidification treatment.

[0046] The solidification treatment comprises for example drying or immobilizing the second concentrate. Drying is advantageous since it allows a further volume reduction. Drying is for example performed in-drum. The second concentrate is filled into one or several drums, and the drum is externally heated. The liquid evaporates, will be condensed and is returned to the liquid effluent storage tanks for treatment by the mentioned evaporation system. After removing a part of the liquid in the drum,

more second concentrate is feed to the drum and the liquid will be also evaporated. This process is continued until in the drum remains a solid block of salts and corrosion products. This drum then, according to related national requirements may be packed e.g. into a High Integrity Container (HIC) or disposed in a deep geological repository.

[0047] Alternatively, the solidification treatment comprises a step of immobilization of the second concentrate. The step of immobilization of the second concentrate comprises for example immobilizing the second concentrate, typically in a cement matrix.

[0048] The first and second evaporation units each comprise an evaporation device arranged for working in a fed batch fashion. The evaporation device of the first unit includes an evaporator and a purification stage e.g. separation trays or packed columns or demisters. The spent liquid effluents is continuously received and heated in the evaporator, so that a liquid phase is evaporated and the liquid effluents form the first concentrate. The vapor phase coming from the evaporator passes through the purification stage, and is submitted therein to one or several purification stages. The vapor phase is condensed and forms the first distillate at the exit of the purification stages. The evaporation device of the second unit is of similar type.

[0049] If the quantity of liquid effluents to be processed is high, the facility can include several first and/or second evaporation units, arranged in parallel to one another.

[0050] Advantageously, the first evaporation unit 20 is located in an effluent treatment building comprising effluent treatment equipment dedicated to one or more nuclear power reactors..

[0051] The purification stage of the first evaporation unit has a height of less than 8 meter, for example of about 5 meters, and can be accommodated in the effluent treatment building as a consequence.

[0052] The recycling unit 24 includes means to recycle the second distillate, for example into the storage tank(s) receiving the batches of spent liquid effluents to be fed to the first evaporation step. Alternatively the means are adapted to recycle the second distillate directly at the first evaporation stage without mixing with the second batch. The distillate can be recycled as well at any other point upstream the first evaporation step.

[0053] Optionally, the facility includes a third evaporation unit 30, adapted for submitting the second concentrate to a third evaporation step and producing a third concentrate and a third distillate. The third evaporation unit 30 preferably comprises means for mixing the third distillate with a third batch of radioactive spent liquid effluents in the storage tanks of unit 18. Alternatively, said means are arranged for recycling the third distillate at the first evaporation stage without mixing with the third batch. It can be recycled as well at any other point upstream the first evaporation step.

[0054] The third evaporation unit 30 includes for example a thin film evaporator. (preferable solution as the

solid concentration is already very high!)

[0055] The second evaporation unit is for example designed for a throughput which is 5 to 50 times lower than the throughput of the first evaporation unit.

[0056] As an example, the first evaporation step processes liquid effluents having a radioactivity concentration of $1.85 \cdot 10^7$ Bq/l. At the end of the first evaporation step, the first distillate has a radioactivity concentration of 1000 Bq/l, and the first concentrate a radioactivity concentration of 10^9 Bq/l. The first distillate is discharged to the sea. At the end of the second evaporation step, the second distillate has a radioactivity concentration of 10^7 Bq/l, and the second concentrate a radioactivity concentration of $1.85 \cdot 10^{10}$ Bq/l.

[0057] As a second example, the first evaporation step processes spent liquid effluents having a radioactivity concentration of $1.85 \cdot 10^7$ Bq/l. At the end of the first evaporation step, the first distillate has a radioactivity concentration of 100 Bq/l, and the first concentrate a radioactivity concentration of 10^8 Bq/l. The first distillate is discharged to the sea. At the end of the second evaporation step, the second distillate has a radioactivity concentration of 10^6 Bq/l, and the second concentrate a radioactivity concentration of $1.85 \cdot 10^{10}$ Bq/l.

[0058] The examples mentioned above refer to design conditions. For real operational conditions the mentioned activity concentrations might be lower. Nevertheless, the same principle is applicable.

Claims

1. Method for processing radioactive liquid effluents of a nuclear power reactor, the method comprising the following steps:

(18) obtaining a first batch of radioactive liquid effluents;

(20) submitting the first batch to a first evaporation step and producing a first distillate and a first concentrate, the first evaporation step bringing given chemical species and/ or radioactivity concentrations in the first distillate in respective predetermined ranges;

(22) submitting the first concentrate to a second evaporation step and producing a second distillate and a second concentrate;

(24) recycling the second distillate at the first evaporation step (20) or upstream.

2. Method according to claim 1, **characterized in that** the radioactivity concentration predetermined range in the first distillate is comprised between 50 and $5 \cdot 10^3$ Bq/l.

3. Method according to claim 1 or 2, **characterized in that** the decontamination factor for radioactivity between the first distillate and the spent liquid effluents

is comprised between $5 \cdot 10^2$ and $5 \cdot 10^3$ at the end of the of the first evaporation step (20).

4. Method according to anyone of the preceding claims, **characterized in that** the second concentrate is transferred to a solid waste conditioning unit (28) and is submitted to a solidification treatment.

5. Method according to claim 4, **characterized in that** the solidification treatment comprises a step of drying and /or a step of immobilization of the second concentrate.

6. Method according to anyone of the claims 1 to 3, **characterized in that** the second concentrate is submitted to a third evaporation step (30), producing a third concentrate and a third distillate, the third distillate being recycled at the first evaporation step (20) or upstream.

7. Method according to anyone of the claims above, **characterized in that** the radioactive liquid effluents have a radioactivity higher than 10^6 Bq/l.

8. Facility for processing radioactive spent liquid effluents of a nuclear power plant, the facility comprising the following units:

- one or several unit (18) for storing a first batch of radioactive spent liquid effluents;

- one or several first evaporation unit (20) for submitting the first batch to a first evaporation step and producing a first distillate and a first concentrate, the first evaporation step bringing given chemical species and/ or radioactivity concentrations in the first distillate in respective predetermined ranges;

- one or several second evaporation unit (22) for submitting the first concentrate to a second evaporation step and producing a second distillate and a second concentrate;

- one or several unit (24) for recycling the second distillate at the first evaporation step or upstream.

9. Facility according to claim 8, **characterized in that** the first evaporation unit (20) is located in an effluent treatment building comprising effluent treatment equipment dedicated to other nuclear power reactors.

10. Facility according to claim 8 or 9, **characterized in that** the first evaporation unit (20) has a purification column having a height of less than 8 meter.

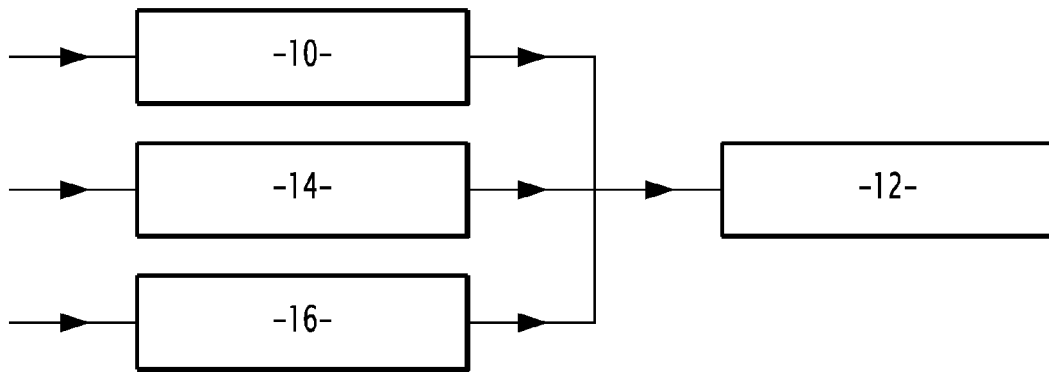


FIG.1

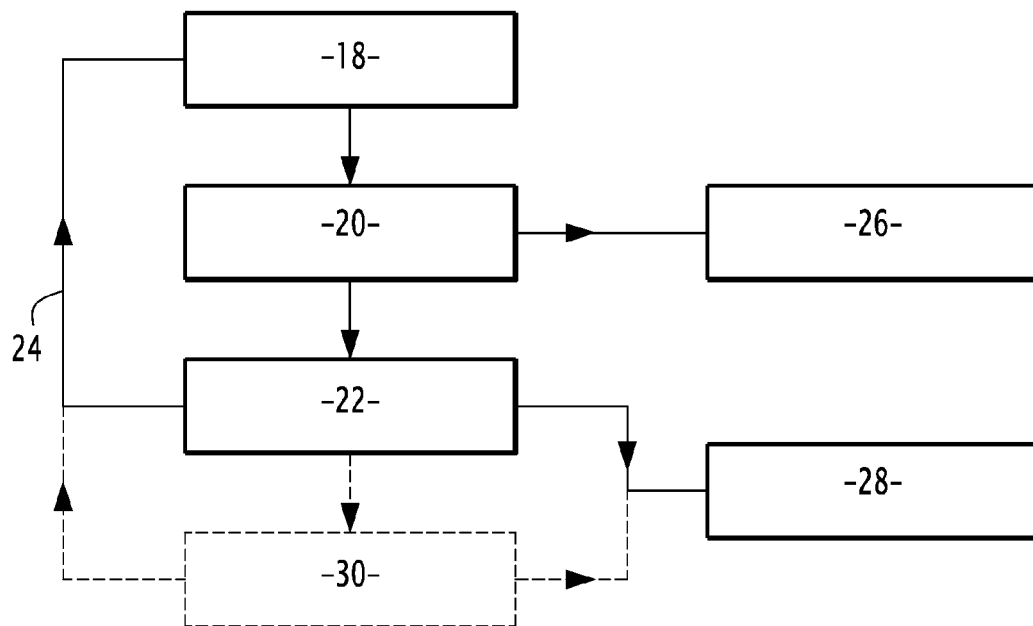


FIG.2



EUROPEAN SEARCH REPORT

Application Number
EP 13 30 6011

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	FR 2 681 719 A1 (FRAMATOME SA [FR]) 26 March 1993 (1993-03-26) * page 12, line 28 - page 18, line 12; figure 3 *	1,4,5,8, 10	INV. G21F9/08 B01D1/00 B01D3/14 G21F9/14 G21F9/16
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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 13 December 2013	Examiner Lohberger, Severin
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 13 30 6011

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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13-12-2013

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